PB82-239666

Community Noise Around General Aviation Airports from the Year 1975 to 2000

Bolt Beranek and Newman, Inc.
Canoga Park, CA

Prepared for

Environmental Protection Agency
Washington, DC

Sep 81

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA

United States
Environmental Protection
Agency

JANUARY 1981

EPA 550/9-82-339

PB82-239666

Community Noise Around General Aviation Airports from the Year 1975 to 2000

Office of Noise Abatement and Control
Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

JANUARY 1981 EPA 550/9-82-339

Report 4442
Project 09587

Community Noise Around General Aviation Airports from the Year 1975 to 2000

William J. Galloway
Ricarda L. Bennett

This report has been approved for general availability. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein. This report does not necessarily reflect the official views or policy of EPA. This report does not constitute a standard, specification, or regulation.

Final Report
Contract: 68-01-5823

.ubmitted to:
Office of Noise Abatement and Control
Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 550/9-82-339	2.	3. RECIPIENT'S ACCESSION NO. PB82 239666
4. TITLE AND SUBTITLE Community Noise Around General Aviation Airports from the Year 1975 to 2000		5. REPORT DATE September 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) William J. Galloway Ricarda L. Bennett		8. PERFORMING ORGANIZATION REPORT NO. 4442
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bolt Beranek and Newman Inc. 21120 Vanowen Street Canoga Park, California 91303		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. EPA 68-01-5823
12. SPONSORING AGENCY NAME AND ADDRESS Office of Noise Abatement and Control Environmental Protection Agency Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED Final, Aug. 1979 - Jan. 1981
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This study forecasts general aviation airport noise from 1975 to the year 2000. It focuses upon noise due to propeller-driven and business jet airplanes that operate at exclusively general aviation airports throughout the country. The results of the study, expressed in terms of geographical area and population within day-night average sound levels of 55 decibels and higher, are estimated at five-year intervals covering this study period.

It is projected that the number of general aviation airplanes in the United States will more than double during these years; however, there will not be a comparable increase in the number of airports. The average sound level for the propeller-driven airplanes is not expected to decrease significantly, but the average sound level associated with the projected business jet fleet will decrease by approximately 16 decibels by the year 2000.

As greater numbers of quieter airplanes are introduced into the general aviation fleet, the area (outside of the immediate airport boundaries) exposed to various noise levels is expected to decrease. This is accompanied by a reduction in the number of people exposed to a day-night average sound level of 65 decibels from 47,000 people in 1975 to zero population in the year 2000. In contrast, there were 1.2 million people exposed to day-night average sound levels of 55 decibels in 1975 with an expected increase to 1.5 million by the year 2000.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
general aviation airports community noise day-night average sound level forecast: general aviation fleet noise propeller-driven airplanes business jet airplanes		

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 124
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

TABLE OF CONTENTS

Page

1.0 SUMMARY 1-1

2.0 INTRODUCTION 2-1

3.0 SOUND LEVELS AND PERFORMANCE OF GENERAL AVIATION AIRPLANES 3-1

3.1 General Considerations 3-1

3.2 Jet Airplanes 3-2

3.2.1 Acoustical Properties 3-2

3.2.2 Noise Certification Proposals . . . 3-3

3.2.3 Sound Levels For Jet Airplanes . . . 3-4

3.2.4 Business Jet Operating Procedures . 3-7

3.3 Propeller-Driven Airplanes 3-18

3.3.1 Acoustical Properties 3-20

3.3.2 Noise Certification Proposals . . . 3-25

3.3.3 Propeller-Driven Small Airplane Sound Levels 3-31

3.3.4 Propeller-Driven Airplane Operating Procedures 3-45

4.0 FORECASTS OF FLEET COMPOSITION, FLIGHT OPERATIONS, AND SOUND LEVELS 4-1

4.1 General Aviation Fleet Forecasts 4-2

4.2 Business Jet Fleet Forecast 4-4

4.3 Business Jet Composite Sound Levels 4-8

4.4 Propeller-Driven Airplane Forecast 4-9

5.0 AIRPORT CLASSIFICATION AND MODELS FOR COMMUNITY NOISE 5-1

5.1 General Considerations 5-1

5.2 Distribution of Airports by Size and Airport Role 5-3

TABLE OF CONTENTS (Cont'd)

Page

5.3 Level of Operations as a Function of Airport Role 5-4

5.4 Population Distribution Around General Aviation Airports 5-15

5.5 Area Models For Community Noise at General Aviation Airports 5-16

5.6 Application of Models to Airports 5-28

6.0 ESTIMATION OF AREAS AND POPULATION EXPOSED TO GENERAL AVIATION AIRPORT NOISE 6-1

6.1 General Assumptions 6-1

6.2 Areas Enclosed by Contours of Equal Day/Night Average Sound Level for 771 Airports . 6-3

6.3 Population Exposed to Various Day/Night Average Sound Levels For the 771 Airport Sample 6-9

7.0 REFERENCES 7-1

8.0 GLOSSARY - SYMBOLS 8-1

LIST OF TABLES

No.		Page
1	Business Jet Noise Levels - FAR Part 36-8 Locations	3-5
2	Propeller-Driven Small Airplanes, 1980 Production Fleet Sound Levels at Appendix F Conditions (HT = 1000 ft)	3-33
3	Propeller-Driven Small Airplanes, 1980 Production Fleet Sound Levels at 6500 Ft. From Brake Release at Takeoff	3-40
4	Propeller-Driven Small Aircraft, 1975 Base Fleet Sound Levels at 6500 Ft. From Brake Release on Takeoff	3-46
5	General Economic Indicators, FAA - 1979 Forecast FY 1980-1991	4-3
6	General Aviation Forecast	4-5
7	Business Jet Fleet Composition at End of Calendar Year	4-7
8	Business Jet Fleet Projections Fraction by Aircraft Model	4-10
9	Extract From National Airport System Plan (NASP) 1978-1987, Federal Aviation Administration	5-7
10	Multiple Regressions Total Operations	5-9
11	Multiple Regressions Local Operations	5-10
12	Multiple Regressions Itinerant Operations	5-11
13	Day/Night Average Sound Level Area Model Parameters In Terms of Average Daily Operations, N, Area In Square Miles	5-26
14	771 Airport Sample - Areas Exposed to Various Day/Night Average Sound Levels	6-5

LIST OF TABLES (Cont'd)

No.		Page
15	771 Airport Sample - Distribution of Airports By Number of Based Airplanes Class	6-10
16	771 Airport Sample - Area Outside Airport Exposed To Various Day/Night Average Sound Levels Segregated By Airport Size and Population Class	6-11
17	771 Airport Sample Population Exposed to Various Day/Night Average Sound Levels	6-12
18	Estimated National Population Exposed To Various Day/Night Average Sound Levels From General Aviation Airports	6-13

LIST OF FIGURES

No.		Page
1	Certification Noise Levels For Business Jet Airplanes	3-6
2	Sound Exposure Level As a Function of Distance - Challenger 600	3-8
3	Sound Exposure Level As a Function of Distance - CITATION I	3-9
4	Sound Exposure Level As a Function of Distance - Gulfstream II	3-10
5	Sound Exposure Level As a Function of Distance - Lear 25	3-11
6	Sound Exposure Level As a Function of Distance - Lear 35	3-12
7	Sound Exposure Level As a Function of Distance - Jetstar II	3-13
8	Sound Exposure Level As a Function of Distance - Sabre 65	3-14
9	Sound Exposure Level As a Function of Distance - Sabre 75A	3-15
10	Business Jet Takeoff Profiles - Maximum Weight . .	3-17
11	Takeoff Profiles For Composite Airplanes	3-19
12	Comparison of Propeller and Engine Noise - Normally Aspirated Reciprocating Engine	3-21
13	Difference Between EPNL and Maximum A-weighted Sound Level For Propeller-Driven Small Airplanes Under Appendix F Tests	3-28
14	Noise Compliance Levels In Terms of Effective Perceived Noise Level (EPNL) and A-Weighted Level (AL)	3-29
15	Maximum A-Weighted Sound Levels For 1980 Airplanes - Appendix F Tests	3-30

LIST OF FIGURES (Cont'd)

No. Page

16 Effective Perceived Noise Levels For 1980 Airplanes Under Appendix F Test Conditions 3-32

17 Sound Exposure Levels As a Function of Slant Distance - Composite Business Jets For Years 1975 To 2000 - Takeoff Thrust and Small Propeller-Driven Airplanes at Takeoff Power 4-11

18 U.S. Civil Airports, January 1, 1980 5-5

19 Frequency Polygon of Basic Utility Airports As a Function of Number of Based Airplanes 5-12

20 Frequency Polygon of General Utility Airports As a Function of Number of Based Airplanes 5-13

21 Frequency Polygon of Basic & General Transport Airports As a Function of Number of Based Airplanes 5-14

22 Fraction of Airports Sorted by Airport Role and Population Class 5-17

23 Day-Night Average Sound Level Contour Areas For 1975 Composite Business Jets, Standard Takeoff Procedures 5-19

24 Day-Night Average Sound Level Contour Areas For Composite Propeller-Driven Small Airplanes 5-20

25 Day-Night Average Sound Level Contour Areas - Mixed 1975 Fleet - 400 Operations Per Day - 1/2% and 2% Jets 5-22

26 Day-Night Average Sound Level Contour Areas 1975 Composite Business Jet - 20 Operations Per Day - Standard and NBAA Takeoff Procedures 5-23

27 Day-Night Average Sound Level Contour Areas For Years 1975 To 2000; 400 Operations Per Day, 2% Jets 5-24

28 Area Enclosed Within Various Contours of Day-Night Average Sound Level As a Function of the Number of Airplanes Based At a Basic Utility Airport 5-31

LIST OF FIGURES (Cont'd)

No.		Page
29	Area Enclosed Within Various Contours of Day-Night Average Sound Level As a Function of the Number of Airplanes Based At a General Utility Airport . . .	5-32
30	Area Enclosed Within Various Contours of Day-Night Average Sound Level As a Function of the Number of Airplanes Based At a Transport Airport	5-33
31	Transport Airports - 2% Jets Change in 55 DNL Contour Area With Time For Fixed Number of Operations	5-34
32	Distance To Sound Exposure Level Contour Closure point - Takeoff Mixed Fleet - 2% Jet For Years 1975 To 2000	5-36
33	Generalized Sound Exposure Level Area Functions - Takeoff	5-38
34	Cumulative DNL Area Outside Utility Airports . . .	6-6
35	125 Transport Airports - Cumulative DNL Area Outside Airports - Mixed Fleet - 2% Jets	6-7
36	771 Airport Cumulative DNL Area Outside Airports .	6-8

1.0 SUMMARY

General aviation consists of all aircraft and operations exclusive of those provided by air carriers and military services. In 1979, general aviation aircraft comprised 98 percent of the total civil aircraft fleet of more than 214,000 aircraft, flew 83 percent of the hours flown by civil aircraft, and 62 percent of the miles flown in civil aviation. General aviation airplanes operate from more than 12,000 airports, as compared to slightly more than 400 served by air carrier airlines.

The number of general aviation airplanes in the United States is projected to grow by a factor of 2.4 between the years 1975 and 2000, although the number of airports available to these airplanes is not projected in this study to grow by any significant amount. The fleet average sound level produced by propeller-driven airplanes is not expected to decrease substantially, and thus the area exposed to community noise from these airplanes is expected to increase. Although the business jet fleet is expected to increase in numbers at rates greater than the average of the fleet as a whole, the business jet fleet average sound levels, due to increasing numbers of quieter airplanes, will decrease markedly as the fleet grows in size. The fleet average reduction in sound levels as a function of time are:

Year	Reduction in Decibels
1975	0
1980	2.0
1985	5.1
1990	10.7
1995	13.7
2000	15.5

The national estimate of the area in square miles, within various day-night average sound levels (excluding the airport proper), is expected to change in the following way:

Year	Area Within Designated Day-Night Average Sound Level in Decibels		
	55	60	65
1975	976	241	14
1980	915	194	5
1985	887	122	3
1990	737	52	0
1995	841	61	0
2000	965	72	0

The national population exposed to different day-night average sound levels is expected to change in the following way:

Year	Population-Thousands Within Designated Day-Night Average Sound Level in Decibels		
	55	60	65
1975	2,256	363	47
1980	1,230	302	20
1985	1,271	254	14
1990	1,218	135	0
1995	1,365	151	0
2000	1,535	176	0

2.0 INTRODUCTION

The provisions of the Noise Control Act of 1972, and its extension, direct the Environmental Protection Agency (EPA) to assess various aspects of aviation noise. Where it finds it appropriate, EPA is directed to make recommendations to the Federal Aviation Administration (FAA) for regulatory actions which EPA believes necessary to protect public health and welfare. General aviation airplanes and their operations are a major portion of the aviation activity in the United States. The purpose of this study is to examine the degree and extent that general aviation produces noise in communities as an aid to EPA in assessing the need for potential regulatory action.

Although general aviation operations are the bulk of operations at all but about a dozen or so air carrier airports, the effect of these operations is incorporated in other EPA studies of air carrier airports and are not considered in this study. About 2000 of the approximately 14,000 landing places in the country serve helicopters and seaplanes exclusively. They are also not part of this study. Military aircraft operations are also excluded from the study, as are the relatively small number of large airplanes, greater than 75,000 pounds gross weight, that are included in the general aviation fleet. The study thus concerns itself with the noise properties of those propeller-driven and business jet airplanes that operate at strictly general aviation facilities throughout the country, and how they might change at five year intervals between the years 1975 and 2000.

Section 3 of this report summarizes the noise characteristics of the propeller-driven and business jet airplanes that constitute the bulk of the general aviation fleet. Sound levels of individual airplanes when measured according to existing noise certification regulations are summarized and compared to different regulatory proposals. Sound levels under typical operating conditions around an airport are summarized, along with descriptions of typical operating procedures. Factors that influence the noise reduction potential of different types of airplanes are discussed.

Forecasts of propeller and jet fleet compositions for the 5 year intervals between the years 1975 and 2000 are projected in Section 4. These projections are based on FAA forecasts until 1991, then extrapolated to the year 2000 by the authors. Airport availability in this period is discussed. The acoustical properties of the airplanes evaluated in Section 3 are used in conjunction with the fleet forecasts to derive composite fleet sound levels for the different time periods of the study.

Section 5 utilizes the results of the previous sections, in conjunction with other analyses, to derive models to relate areas enclosed within constant contours of day/night average sound level. These models are developed for three different classes of airports. The three classes of airports were selected to be consistent with the FAA categories of basic utility, general utility, and transport airports. These airports differ from each other in size, scale of operations, and mixture of airplane types that the airports are capable of accepting. Models for scale of operations are derived from data contained in the National Airport System Plan developed by FAA. The same data, in conjunction with information on the geographic disposition of a sample of 771 airports relative to the communities they serve, are used to define three population classes associated with airports rural, suburban-rural, and urban.

The information developed in the previous sections is used in Section 6 to derive estimates of aggregate areas around airports exposed to different day/night average sound levels in the five year intervals between the years 1975 and 2000. The populations contained within these areas are then estimated. The analyses are based on the 771 airport sample, then extrapolated to a national estimate.

3.0 SOUND LEVELS AND PERFORMANCE OF GENERAL AVIATION AIRPLANES

3.1 General Considerations

Sound levels produced on the ground in the vicinity of an airport are dependent on the basic sound producing characteristics of each airplane at various power settings, and the height and airspeed of the airplane at various points along its flight path. The basic noise generating characteristics of an airplane are established primarily by the design of the power plant and its installation. The basic aerodynamic performance of the airplane and the piloting procedures used in various flight regimes establish the height, airspeed, and power setting at various points along the flight path.

Published sound levels for airplanes, such as those listed in FAA Advisory Circulars 36-1B, 36-2A and 36-3A, are of great use in comparing the levels of one airplane with another under controlled test conditions, but are of little use in studying airport noise. There are two reasons for this statement. First, the test conditions and measurement locations for certification purposes are generally not representative of normal operations for general aviation (GA) airplanes. Further, the certification data provide information at only one location for propeller-driven airplanes and only three locations for jets. Second, the acoustical measures used for certification, maximum A-weighted sound level (ALM)* for props and effective perceived noise level (EPNL) for jets, cannot be used directly to obtain A-weighted sound exposure level (SEL), the basic measure used to compute day-night average sound level (DNL), the preferred measure of community noise.

---

*See the appended glossary for definitions of acoustical and aerodynamic terms used in this report.

The following paragraphs summarize the acoustical and performance characteristics of jet and propeller-driven airplanes that constitute the existing general aviation fleet.

3.2 Jet Airplanes

Jet airplanes considered in this study are turbojet or turbofan airplanes of less than 75,000 pounds gross weight that are generally described as the "business jet" fleet. (Larger transport category airplanes and military jets operated in civilian use, a total of approximately 200 airplanes in the 1975 base year, although considered as general aviation by FAA, are not included in the study.) The business jet fleet, while constituting about one percent of the total general aviation fleet in 1975, flew more than twice the number of hours than the GA fleet average. Between 1975 and 1980 the jet fleet had a compound growth rate of 13.5 percent per year, compared to 4.8 percent for the GA fleet as a whole.

3.2.1 Acoustical Properties

The original business jets, introduced in the 1960's, such as Sabreliners, Jet Commanders, Jetstars, and Learjet 20 series, constitute the bulk of the 1975 base year fleet. They are powered by turbojet engines in the 3000 pound static thrust class and are by far the noisiest GA airplanes. A low by-pass ratio turbofan engine, producing somewhat lower sound levels, was subsequently used on the Falcon 20 (and later on the Sabreliner 75A). Major reduction in sound levels of the order of 10 to 20 decibels came with the introduction of the moderate by-pass ratio JT15 engine on the Citation in the early 1970's, and with the TFE731 engine which came into service in 1975 on the Lear 35.

By 1980 more than 90 percent of new business jet production airplanes used versions of these two engines. Notwithstanding their lower sound levels, the primary incentive for use of turbofan engines is their greatly improved fuel efficiency as compared to turbojets. In the decade of the 1980's essentially all new business jets will be powered by turbofan engines, with newer, higher by-pass engines such as the ALF-502 and CF-34 coming into use.

3.2.2 Noise Certification Proposals

Noise certification requirements for "new" type designs of turbojet airplanes were first promulgated by FAA as FAR Part 36 in 1969[1/]. This requirement had little effect on business jet noise, since most "new" airplanes are derivations of older type designs. (Only one new U.S. manufactured business jet airplane type certificate was issued between 1969 and 1980.) The FAA's adoption of a "new production" regulation required all jets manufactured after 1973 to comply with the 1969 noise limits[2/]. With one minor exception, all business jets managed to show compliance with these limits. The noise limits for newly type certificated turbojet airplanes were reduced in 1977 to what are now designated as "Stage 3" limits[3/]. (The original 1969 noise limits are termed

"Stage 2.") As yet no new U.S. business jet airplane types have been certificated under these requirements.

Despite not having to meet the Stage 3 noise limits, essentially all current production turbofan business jets can comply with these requirements, many by substantial margins.

In 1976 EPA submitted recommendations to FAA for a time-phased reduction in the certification noise limits for jet airplanes[4]. The essence of the proposals, with regard to new type designs, was that noise limits should be reduced at five year intervals. Three proposals for new limits were associated with "current technology," "available technology," and "future technology." The proposed limits were to apply to airplanes whose dates of application came after 1 January 1975, 1980, and 1985. In EPA terminology these are referred to as "75 FAR 36," "80 FAR 36," and "85 FAR 36," respectively. The adoption by FAA of amendments 36-7 and 36-8 established Stage 3 noise limits significantly higher for GA aircraft than the EPA proposal 75 FAR 36. Subsequently, FAA rejected EPA proposals 80 FAR 36 and 85 FAR 36 which would have established new Stages 4 and 5.

3.2.3 Sound Levels For Jet Airplanes

Effective perceived noise levels under FAR Part 36 certification conditions for current business jet airplanes are listed in Table 1. These same data are also shown in Figure 1, with airplanes identified by number from Table 1. The certification noise limits proposed by EPA in its 1976 proposal are also shown on Figure 1. As seen in Figure 1, the sideline sound levels for turbofans are on the order of 20 decibels lower than the sound levels measured for earlier turbojets with comparable gross

TABLE 1
BUSINESS JET NOISE LEVELS - FAR PART 36 - 8 LOCATIONS

Aircraft	Engine Models	Weight	Effective Perceived Noise Level			BFL ft Std Day
		(1000 lb)	T/O dB	SL dB	Appch dB	
1. Challenger CL-600	ALF-502L	36.0	81.6	89.3	91.2	4700
2. Citation I	JT15D-1A	11.5	77.7	86.1	87.4	2930
3. Citation II	JT15D-4	13.3	80.1	88.1	90.5	2990
4. Corvette SN601	JT15D-4	15.4	81.3	85.4	89.5	5120
5. Commander 1121	CJ610-5	18.5	98.9	104.2	106.7	4950
6. Falcon 10	TFE-731-2-1C	18.3	83.4	86.4	95.0	4470
7. Falcon 20	CF 700-2D-2	28.7	90.0	91.4	102.7	4950
8. Falcon 50	TFE-731-3-1C	38.8	84.3	90.6	97.1	4900
9. Gulfstream II	Spey 511-8	62.0	91.0	103.6	97.0	5800
10. Hansa 320	CJ 610-9	20.3	97.9	105.0	106.0	5500
11. HS125-600	Viper 601-22	25.0	96.3	104.2	102.3	5350
12. HS125-700	TFE-731-3R	24.8	87.6	93.0	96.3	5800
13. Jetstar I	JT12A-8	42.0	99.0	103.3	107.5	6000
14. Jetstar II	TFE-731-3	44.3	88.6	91.6	97.2	6525
15. Learjet 23	CJ610-1	12.5	90.1	103.4	96.4	4300
16. Learjet 24D	CJ-610-6	13.5	91.9	104.0	96.4	3900
17. Learjet 25	CJ610-8A	15.0	96.2	103.8	97.6	5200
18. Learjet 35/36	TFE-731-2-2B	17.0	83.4	86.7	91.2	4785
19. Sabreliner 40	JT12A-8	19.6	93.4	100.2	98.2	5400
20. Sabreliner 60	JT12A-8	20.2	94.3	100.1	98.2	5050
21. Sabreliner 65	TFE-731-3R-1D	24.0	84.0	93.0	90.6	5895
22. Sabreliner 75A	CF 700-2D2	23.3	90.9	91.4	99.9	4620
23. Westwind 1123	CJ 6109	20.7	97.9	105.0	105.7	4950
24. Westwind 1124	TFE-731-3	22.9	88.4	87.7	93.0	5250

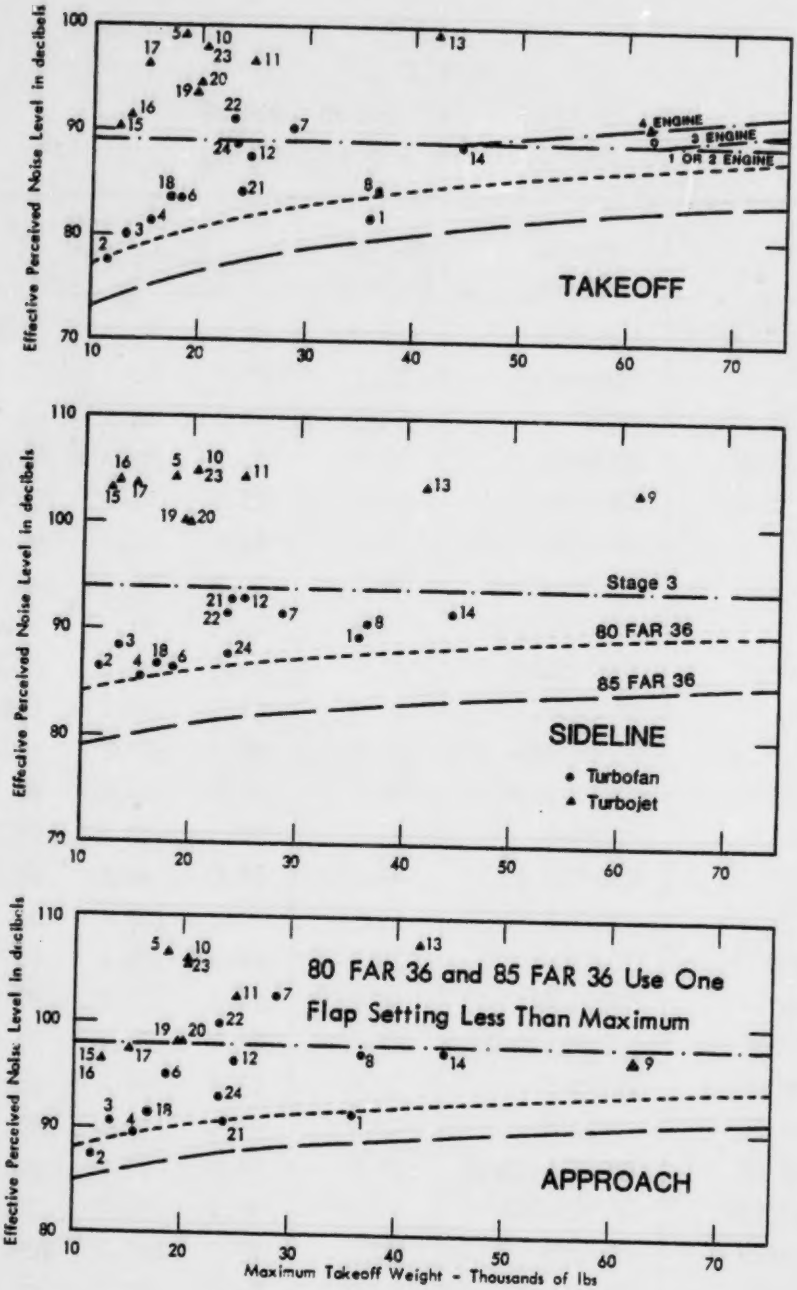

FIGURE 1. CERTIFICATION NOISE LEVELS FOR BUSINESS JET AIRPLANES

weight. Sound levels under approach conditions are as much as 10 to 15 decibels lower for the turbofan airplanes at comparable weights.

The large differences in sound levels between the older turbojets and the newer turbofans will cause major changes in the fleet average sound levels over time. The large increase anticipated in fleet size will consist of the much quieter airplanes. The increases in fuel costs anticipated with time can be expected to cause a phasing out of straight turbojets, or their conversion to turbofan engines (as is already happening).

In order to calculate fleet average SEL functions of slant distance for use in airport noise analyses, the SEL/slant distance functions for airplanes with each major engine type are required. Figures 2 to 9 provide such functions for airplanes having each engine type in the existing fleet.

3.2.4 Business Jet Operating Procedures

3.2.4.1 Approach

Noise certification procedures specify that sound levels during an approach to landing be measured while the airplane is descending along a 3 degree glide path in landing configuration (gear and flaps down), at a speed that is 1.3 times stall speed plus 10 knots, at maximum landing weight[5]. Under normal operations the airplane will often be less than maximum landing weight, and airspeed will be lower. For practical purposes, this study assumes a 3 degree approach is used and that sound levels produced are for the same thrust and airspeed as used in certification.

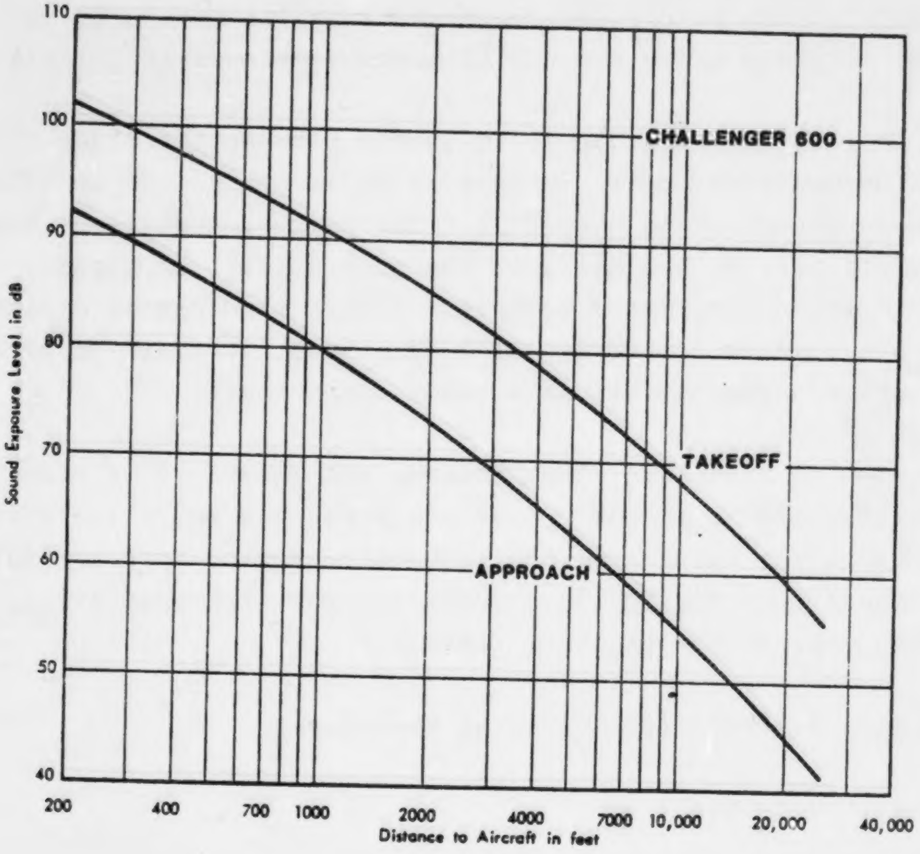

FIGURE 2. SOUND EXPOSURE LEVEL AS A FUNCTION OF DISTANCE - CHALLENGER 600

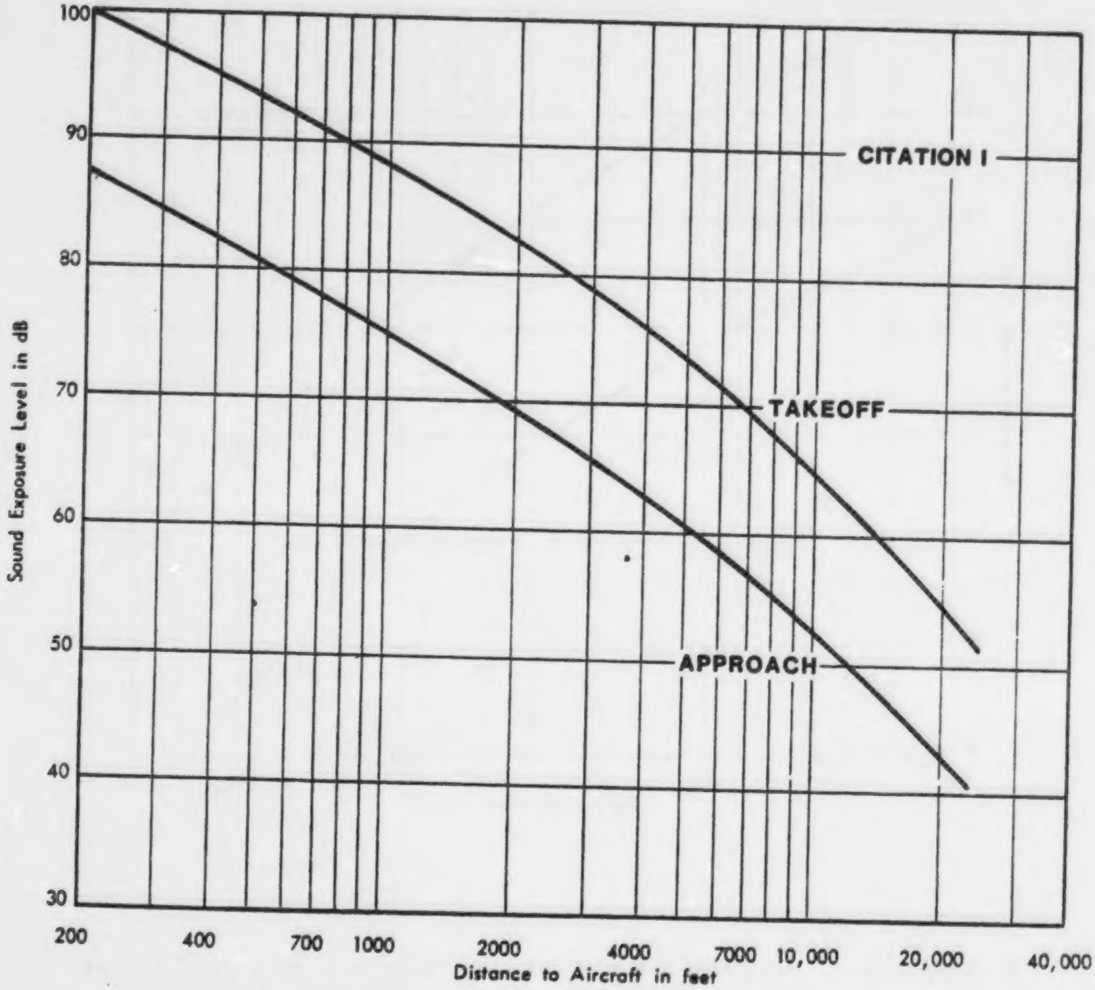

FIGURE 3. SOUND EXPOSURE LEVEL AS A FUNCTION OF DISTANCE - CITATION I

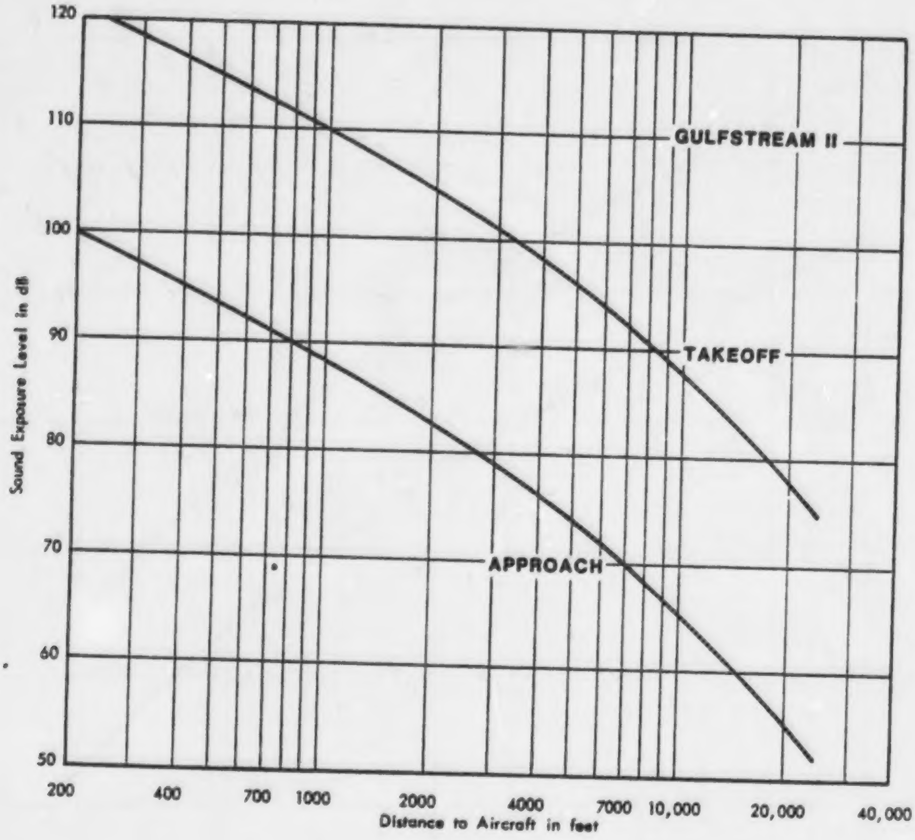

FIGURE 4. SOUND EXPOSURE LEVEL AS A FUNCTION OF DISTANCE - GULFSTREAM II

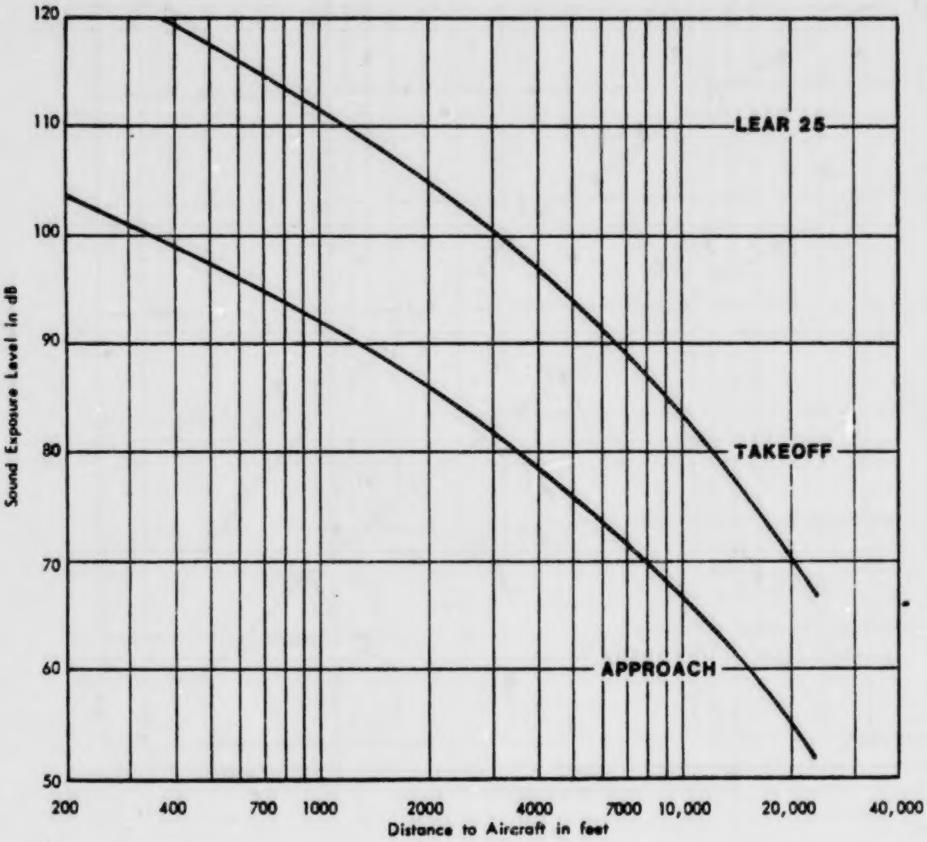

FIGURE 5. SOUND EXPOSURE LEVEL AS A FUNCTION OF DISTANCE - LEAR 25

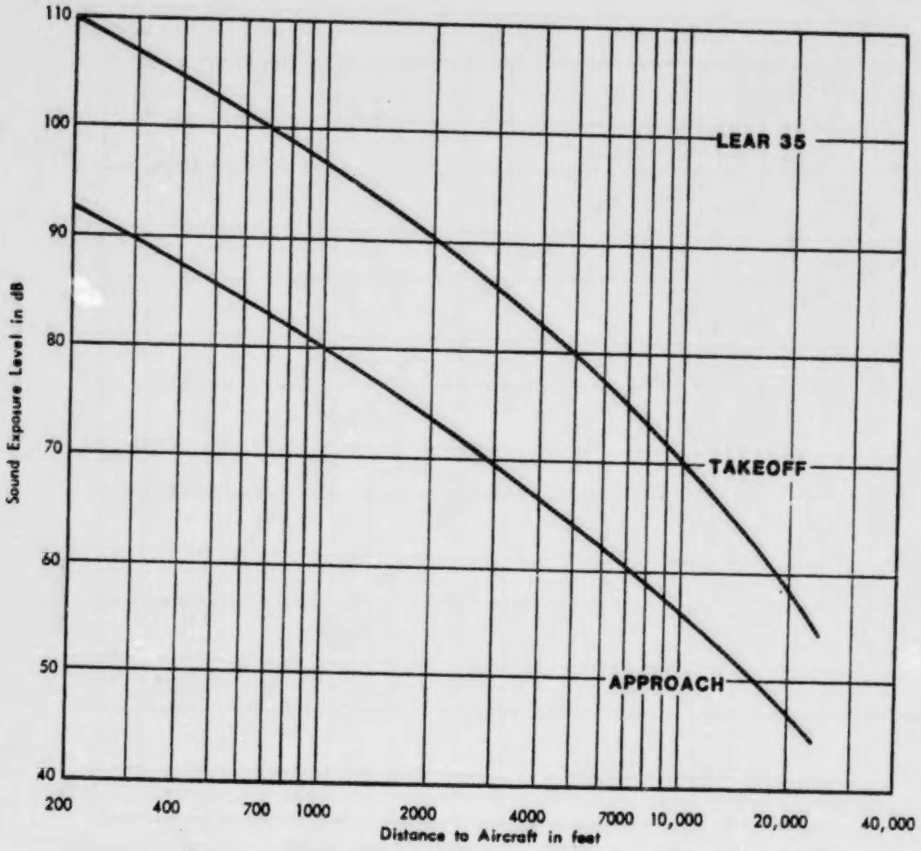

FIGURE 6. SOUND EXPOSURE LEVEL AS A FUNCTION OF DISTANCE - LEAR 35

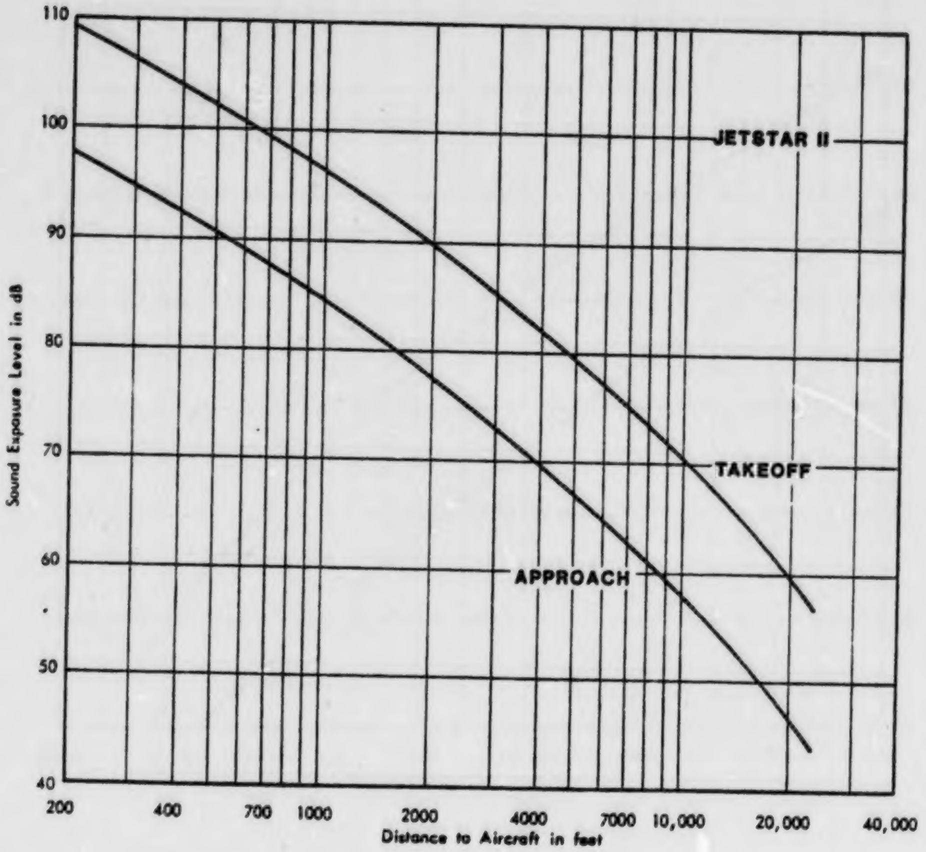

FIGURE 7. SOUND EXPOSURE LEVEL AS A FUNCTION OF DISTANCE - JETSTAR II

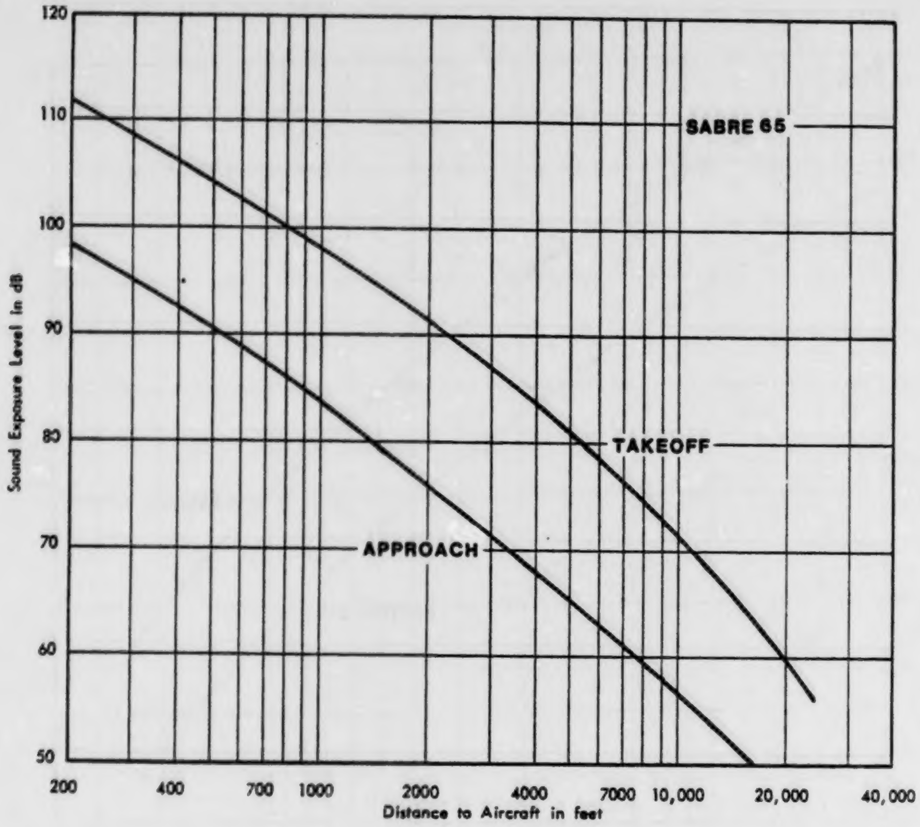

FIGURE 8. SOUND EXPOSURE LEVEL AS A FUNCTION OF DISTANCE - SABRE 65

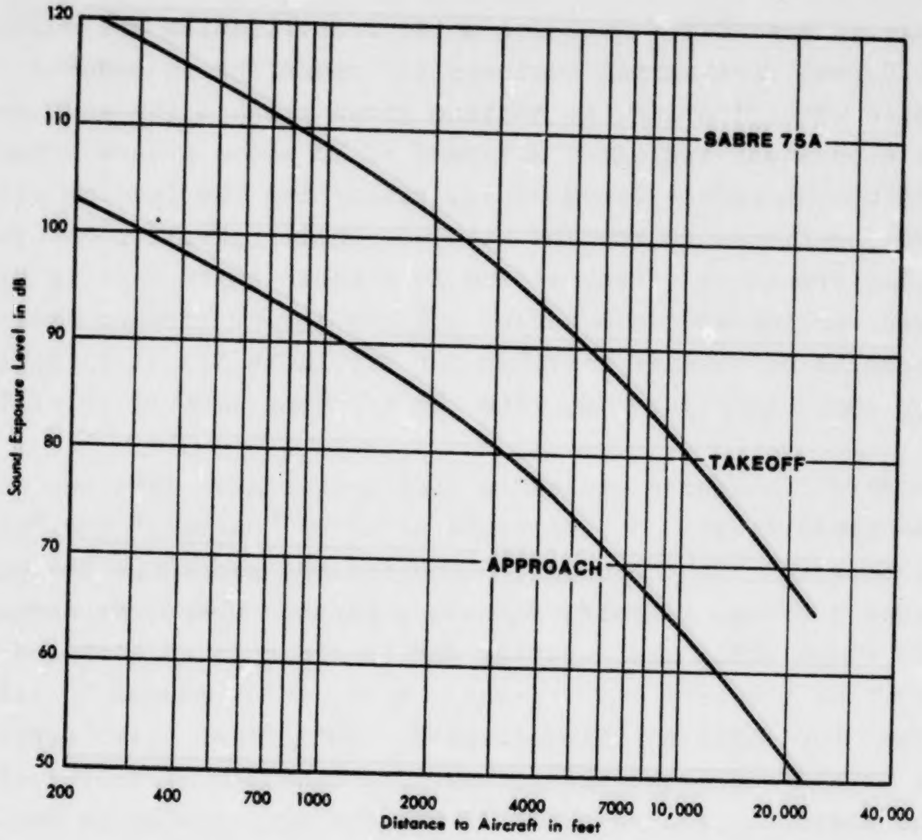

FIGURE 9. SOUND EXPOSURE LEVEL AS A FUNCTION OF DISTANCE - SABRE 75A

3.2.4.2 Takeoff

Takeoff procedures used for noise certification are quite different from normal business jet operating procedures. During noise certification, at maximum gross weight, the airplane climbs at a constant indicated airspeed of 10 knots greater than the engine-out safety speed of V_2, retracting the landing gear, but leaving flaps, if any are used, in their takeoff position. This climb procedure often results in a cabin angle that is higher than considered comfortable, and can impair forward visibility. Examples of takeoff profiles for airplanes listed in Table 1 are shown in Figure 10, with the airplane identifier of Table 1.

Takeoff procedures typically used by business jets can be described either as "unconstrained," or "normal," and "noise abatement." In the usual, unconstrained procedure the pilot makes a normal liftoff, maintains takeoff power, retracts gear and flaps while accelerating during climb to an airspeed that provides the best lift-to-drag ratio, then reduces to climb power for climb at this airspeed. This final climb configuration is usually achieved before reaching a height of 1500 feet above the airport. Average takeoff weights are usually on the order of 85 percent of maximum takeoff weight. Final climb speeds are from 220 to 250 knots, in contrast to the V_2 + 10 speeds used in certifications that range from around 130 to 150 knots until 6500 m from brake release. The resulting profile, at least in the vicinity of the airport, is usually substantially lower than that for noise certification purposes.

Where noise sensitive areas are close to an airport many pilots use one of two procedures recommended by the National Business

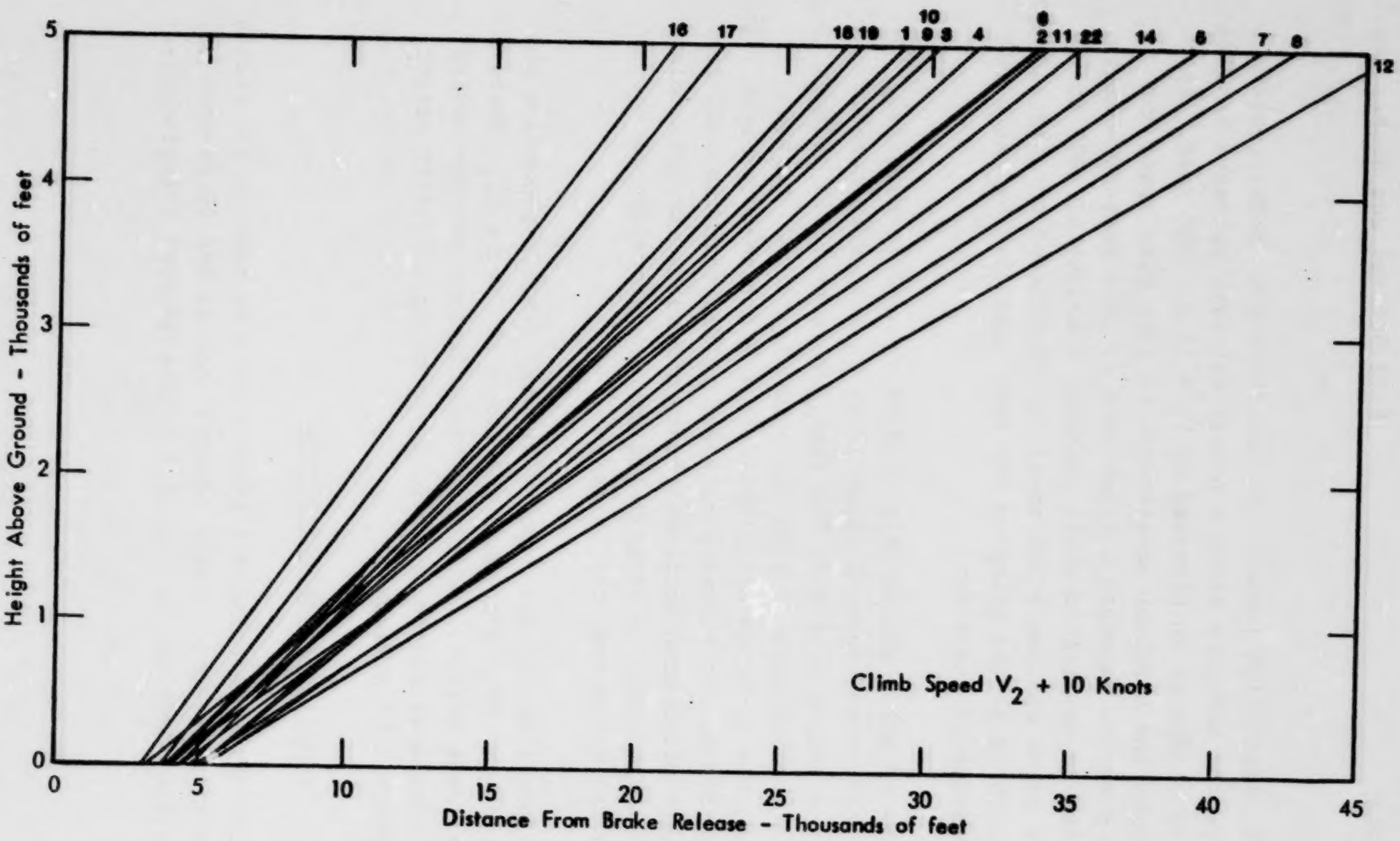

FIGURE 10. BUSINESS JET TAKEOFF PROFILES - MAXIMUM WEIGHT

Aircraft Association (NBAA). In the "standard" noise abatement procedure the airplane makes a normal takeoff, retracts landing gear, and climbs at an airspeed of V_2 + 10 to 1500 feet. At this height the airplane accelerates to zero flap speed and reduces power to maintain a climb rate of 1000 feet-per-minute. This climb is maintained until reaching a height of 3000 feet, at which point maximum climb power is established and the airplane is accelerated to the airspeed for best lift-to-drag ratio for the remainder of the climb.

A "close-in" noise abatement procedure is also recommended. In this procedure the initial climb is at V_2 + 10 with takeoff power to a height of 500 to 700 feet, where power is reduced to maintain a climb rate of 1000 feet-per-minute. On reaching 1500 feet the airplane accelerates to the airspeed for zero flaps, retracts flaps, and climbs with power to maintain the 1000 feet-per-minute climb rate until reaching 3000 feet. At this point maximum climb power is established and the procedure is the same as for the normal procedure.

Nominal profiles for the "unconstrained" takeoff procedure and the "close-in" NBAA procedure are shown in Figure 11. These profiles were derived for a composite airplane representative of the airplanes listed in Table 1, assuming a takeoff weight of 90 percent of maximum.

3.3 Propeller-driven Airplanes

Propeller-driven airplanes ("props") of less than 12,500 pounds maximum gross weight ("small" props) constituted 99 percent of the 161,000 airplanes in the 1975 active general aviation fleet

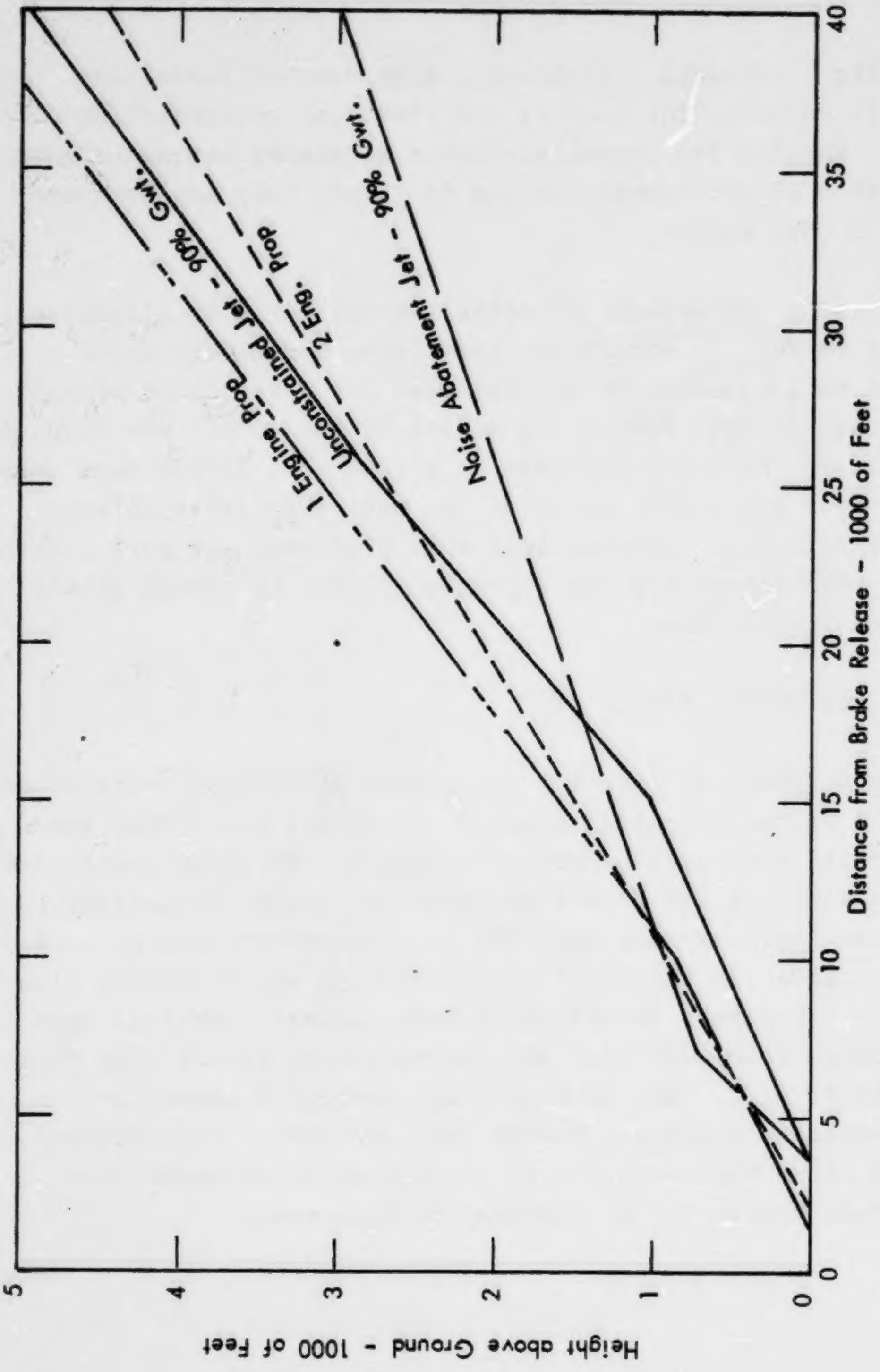

FIGURE 11. TAKEOFF PROFILES FOR COMPOSITE AIRPLANES

(jets being 1 percent). Although 1.6 percent of these have turboshaft engines, the bulk of the fleet use reciprocating engines. While a few propeller-driven airplanes having weights greater than 12,500 operate in the GA fleet, they are not considered in this study.

When assessing the effects of noise control for prop airplanes, it should be kept in mind that fleet noise levels for these airplanes will continue to be dominated for a very long time by existing airplanes. During the decade of the 1970's new airplanes were added to the existing fleet at a rate of a little more than 6 percent per year, with an attrition rate of older airplanes no longer active at somewhat less than 2 percent per year. With adequate maintenance one can expect airplanes to remain active for an indefinite time.

3.3.1 Acoustical Properties

The noise produced by existing small prop airplanes, using either turboshaft or reciprocating engines, is in all but a very few cases totally dominated by propeller noise. Weighted sound levels for these aircraft are highly dependent on propeller helical Mach number (varying with the 18th to 24th power), and to a lesser extent on blade tip thickness ratio (varying approximately with the 3rd to 4th power, depending on Mach number). Helical Mach numbers range from 0.75 to 0.95, and thickness ratios vary from about 0.04 to 0.12. The obvious noise control measures are to reduce propeller diameter, reduce rpm, and reduce tip thickness. Figure 12 shows the variation in A-weighted sound level with helical Mach number for an average tip thickness.

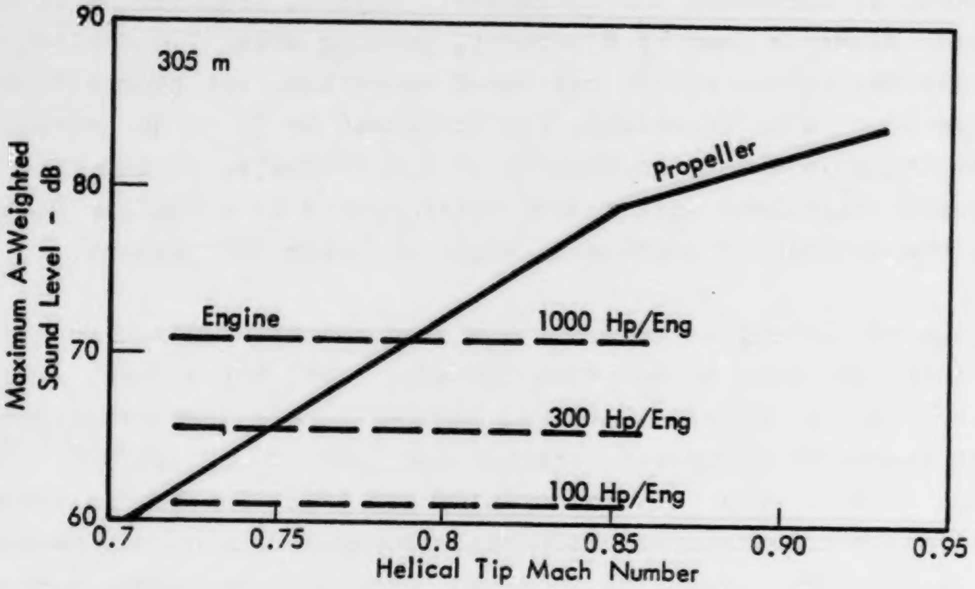

FIGURE 12. COMPARISON OF PROPELLER AND ENGINE NOISE - NORMALLY ASPIRATED RECIPROCATING ENGINE

It is common practice to reduce diameter by cutting of existing blades without changing blade design. While this reduces tip speed, it increases tip thickness. Typical practice is to cut blade diameter down by 8 percent, gaining about 7.5 decibels in noise reduction, due to tip speed reduction, but negate 4 decibels of this by increasing tip thickness by 35 to 40 percent, resulting in a net improvement of 3.5 decibels. Using three-bladed propellers will reduce noise levels in a similar fashion, at the expense of increased weight or lower performance.

Reduction of engine rpm will also reduce tip Mach number and thus noise. In order to maintain the same rated horsepower, some direct drive engines (0-470-U, 0-540-J3) have been redesigned to use increased compression ratios and reduced rpm (2575 to 2400 rpm, 2600 to 2400 rpm). The other approach is to use geared propeller drives to operate at a fraction, typically 2/3, of engine rpm. This is a very expensive approach, used only on large, turbocharged engines. For example, the only geared engine used in current production aircraft is rated at 375 horsepower. Thus the option of geared engines is not available today, for 99 percent of currently produced airplanes with reciprocating engines.

Reduction in rpm, holding propeller diameter and horsepower constant, requires a change in propeller design if performance is not to be compromised. With conventional NACA 16 or 65 series airfoils, takeoff thrust increases with increases in blade activity factor, up to about 150 per blade, while cruise efficiency decreases, therefore not much is gained by changing blade plan form. On the other hand, for takeoff climb, if the pitch of the conventional propeller is increased to absorb full takeoff power at the reduced rpm, the power coefficient and advance ratio increase in such a way that propeller efficiency increases, providing more thrust, and thus greater rates of climb. Reduction in cruise efficiency is only a matter of 1 to 2 percent for these situations.

It is likely that more engines will be introduced with lower operating rpm. The usual practice in the past has been to develop a range of engines based on a fixed displacement. Lower horsepower versions use low compression ratios and lower rpm. Higher horsepower versions are introduced by increasing compression ratio and rpm, and finally by turbocharging the engine. In the most developed cases propeller reduction gears are used, with a considerably higher engine rpm. In the Teledyne Continental 520 series, different versions ranging from 285 to 435 horsepower have been produced. The obvious next step is to derate engines by lowering rpm to provide engines that can replace the higher horsepower versions of smaller displacement series. In order to make this attractive to airplane designers, engine weights will also have to be reduced. Continental has announced new versions of the 520 series that use magnesium in place of aluminum for some parts, yielding a 10 percent weight reduction. One version of this series is a 250 horsepower engine operating at 2400 rpm instead of the nominal 285 horsepower at 2700 rpm. The obvious way to obtain lower propeller tip speeds without geared engines is to use the higher displacement, lower weight engines at lower rpms.

In the past few years there has been greatly increased interest in developing propellers with higher lift airfoil sections, such as the GAW-1 in this country and the ARA-D in England. The principal advantage of these airfoils is to provide higher lift coefficients at lower activity factors, i.e. at smaller chords. This provides a higher thrust at low speeds, and some minor improvement in cruise efficiency. Neither of these points directly influences the noise characteristics for small airplanes (less than 400 horsepower per engine) where blade section characteristics and plan form have little effect on noise. What they do offer is the ability to obtain good performance at lower engine speeds, when engines become available. (This is substantially more important for turboprops, as discussed below.)

The concept of muffling the engine to achieve noise reduction in small reciprocating engined airplanes has not received much attention. This is because engine noise is largely masked as long as propeller tip speeds are such that helical Mach numbers are greater than about 0.75. As tip speeds drop, better muffling is required. At the present time, engine and propeller noise about equally contribute to the sound levels at the low helical Mach numbers obtained during takeoff of airplanes with fixed-pitch propellers. During cruise climb, the noise levels for the two current production airplanes using geared engines are completely controlled by engine noise, which is up to 9 decibels higher than propeller noise. Note that present Appendix F noise certification tests of FAR 36 do not demonstrate this situation since the test conditions require both high rpm and forward airspeed, which causes the helical Mach number to be high enough that propeller noise totally dominates.

Much greater flexibility is available to reduce noise from turboprop engines since they already incorporate a sophisticated gear box to reduce engine rpm to speeds appropriate for propellers (i.e. 33,000 to 2,000 rpm is a typical reduction). Newer versions of the PT-6 and TPE-331 engines have gearing to reduce propeller rpm to below 1600. Even lower propeller speeds will shortly be available with engines now being designed for commuter airplanes.

3.3.2 Noise Certification Proposals

In 1974 FAA issued Subpart F and Appendix F to FAR Part 36[6/]. This amendment established sound level limits and test procedures for propeller-driven small airplanes. These limits specify a maximum A-weighted sound level of 82 decibels for aircraft with type certification applications after October 1973, and 80 decibels after January 1975. A "production" rule was also established with a maximum of 80 decibels for all airplanes receiving new airworthiness certificates after January 1980, regardless of type certificate date.

Just prior to FAA issuance of Appendix F, EPA submitted recommendations to FAA for a regulation which included two major features not incorporated into the FAA regulation. One recommendation was to use effective perceived noise level (EPNL) instead of A-weighted sound level. The other was a specification of three different sound level limit proposals, termed "current," "available," and "future." The first two were time-phased with the two limits proposed by FAA in Appendix F. The third was proposed to apply to airplanes having new type certificate applications after January 1980. In 1977 FAA issued its response to EPA in which it accepted minor modifications to the existing Appendix F, but rejected the use of EPNL and the limits proposed by EPA[7/].

As in the case for jet airplanes, the issuance of a new type certificate for prop airplanes is a rare occurrence. In general, new models of airplanes are certificated under amendments to older type certificates, some more than 25 years old*. Thus the primary impact of noise certification on manufacturers came with the 1980 requirement for issuance of new airworthiness certificates. The problem of compliance, however, was eased by FAA in the 1977 amendment to FAR Part 36.

The original test requirement of Appendix F specified testing with the engine operating at maximum continuous power. This power is established by the engine manufacturer. The 1977 amendment to Appendix F specifies operation at the "highest power in the normal operating range," as defined for each airplane by the airplane manufacturer. The manufacturer is thus allowed to specify a lower rpm and power in the "normal operating range," applicable to level flight conditions, and by so doing reduce the sound levels for Appendix F test purposes. No compromise is made for takeoff performance, no change in normal cruise performance occurs, no modification is required of the aircraft other than an instrument marking, and no change in community noise results. A number of airplanes not able to comply with the 1980 limits before this change in power specification now are in compliance without any change in the airplane. Since the Appendix F test yields sound levels (without performance adjustments) that are from 4 to 11 decibels greater than those produced at the same height during normal operations around an airport, as discussed below, the result of this amendment is somewhat academic in terms of community noise.

---

*In some instances a manufacturer may choose to obtain a new type certificate for a newer model of an old basic design to improve its position with respect to product liability.

It is instructive to consider what effect the EPA proposals would have had if adopted. In its 1974 proposal EPA, in effect, assumed that EPNL is a constant 11 decibels greater than A-weighted sound level. For this to be true would require airplanes of the same speed to have identical spectra, and, with the more than two-to-one speed ratio between higher performance and lower performance airplanes, the duration adjustment incorporated in EPNL would have to be exactly offset by spectral changes in perceived noise level (PNL). This is not the case and this is demonstrated by the data in Figure 13 where the difference in EPNL and maximum A-weighted sound level are shown for a representative sample of current production airplanes.

The empirical conversion between EPNL and maximum A-weighted sound level obtained in Figure 13 may be used to compare the relative stringencies of the FAA regulation and the EPA proposals. Two such cases are shown in Figure 14. The upper set of curves shows the EPA proposed limits for "current" and "available" technology in terms of EPNL, as compared to the FAA 1980 production rule, converted to EPNL. Clearly the existing FAA rule requires lower sound levels. An alternate comparison is to convert the EPA "future" technology proposal to maximum A-weighted sound level and compare it to the existing FAA regulation. This is shown by the lower set of curves in Figure 14.

The degree of compliance with the 1980 regulatory requirements by the current production fleet is shown in Figure 15 where certified Appendix F sound levels are shown in relation to the sound level limits as a function of airplane weight. While a

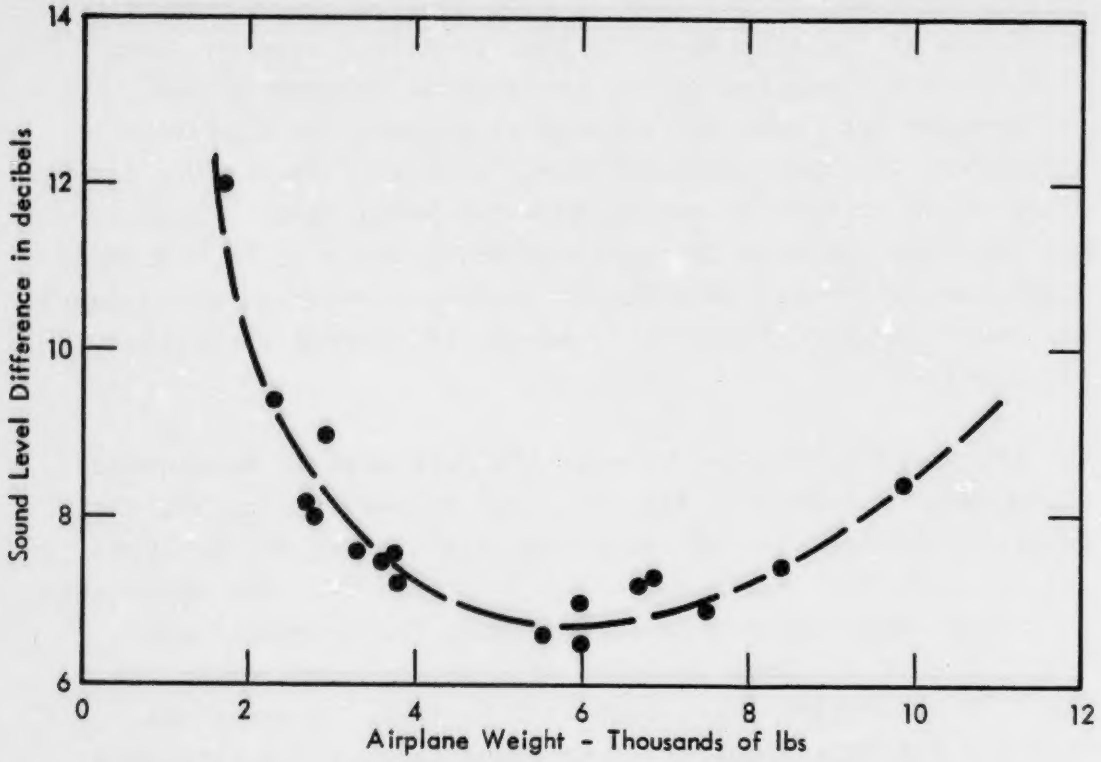

FIGURE 13. DIFFERENCE BETWEEN EPNL AND MAXIMUM A-WEIGHTED SOUND LEVEL FOR PROPELLER-DRIVEN SMALL AIRPLANES UNDER APPENDIX F TESTS

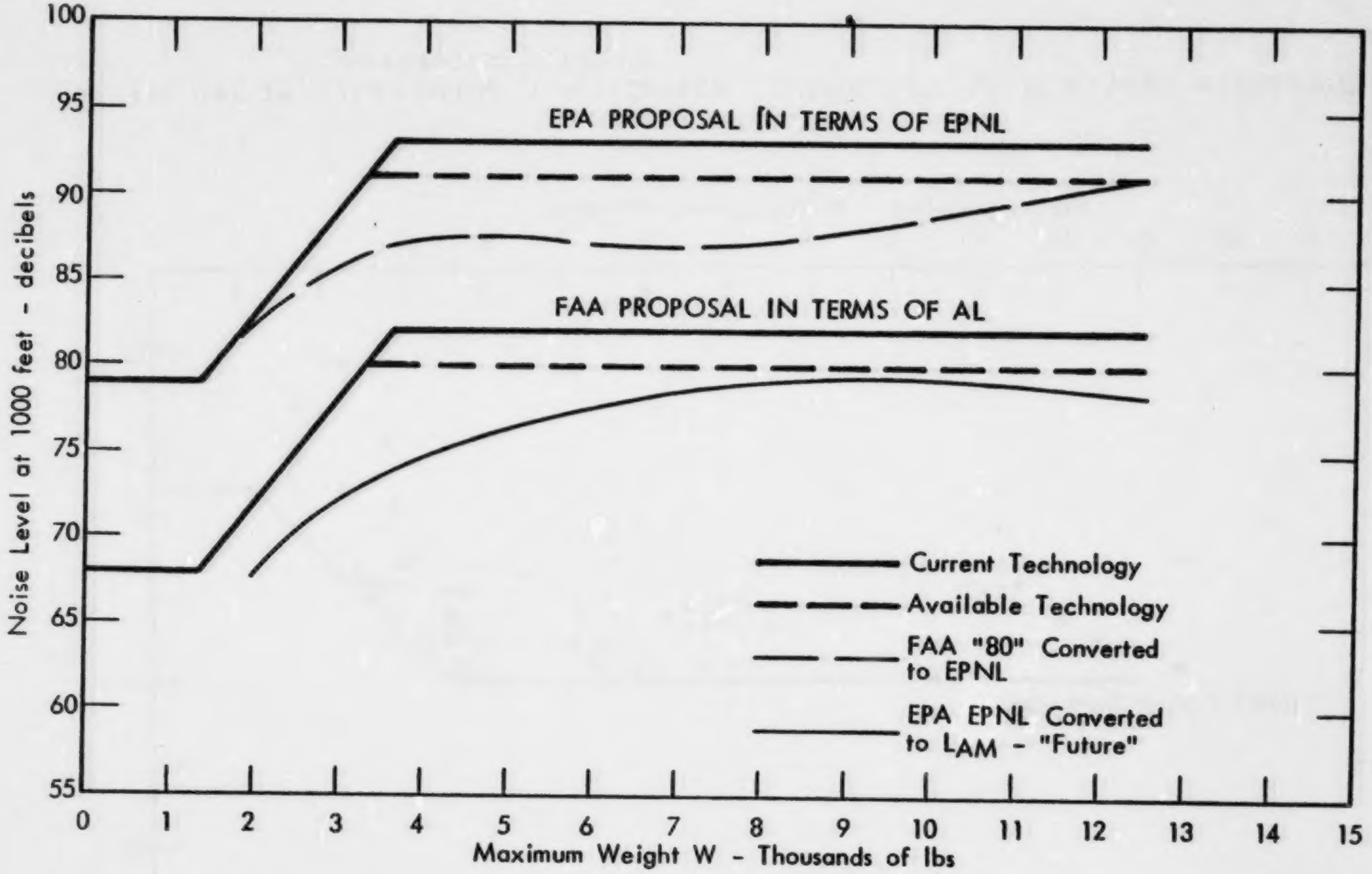

FIGURE 14. NOISE COMPLIANCE LEVELS IN TERMS OF EFFECTIVE PERCEIVED NOISE LEVEL (EPNL) AND A-WEIGHTED LEVEL (AL)

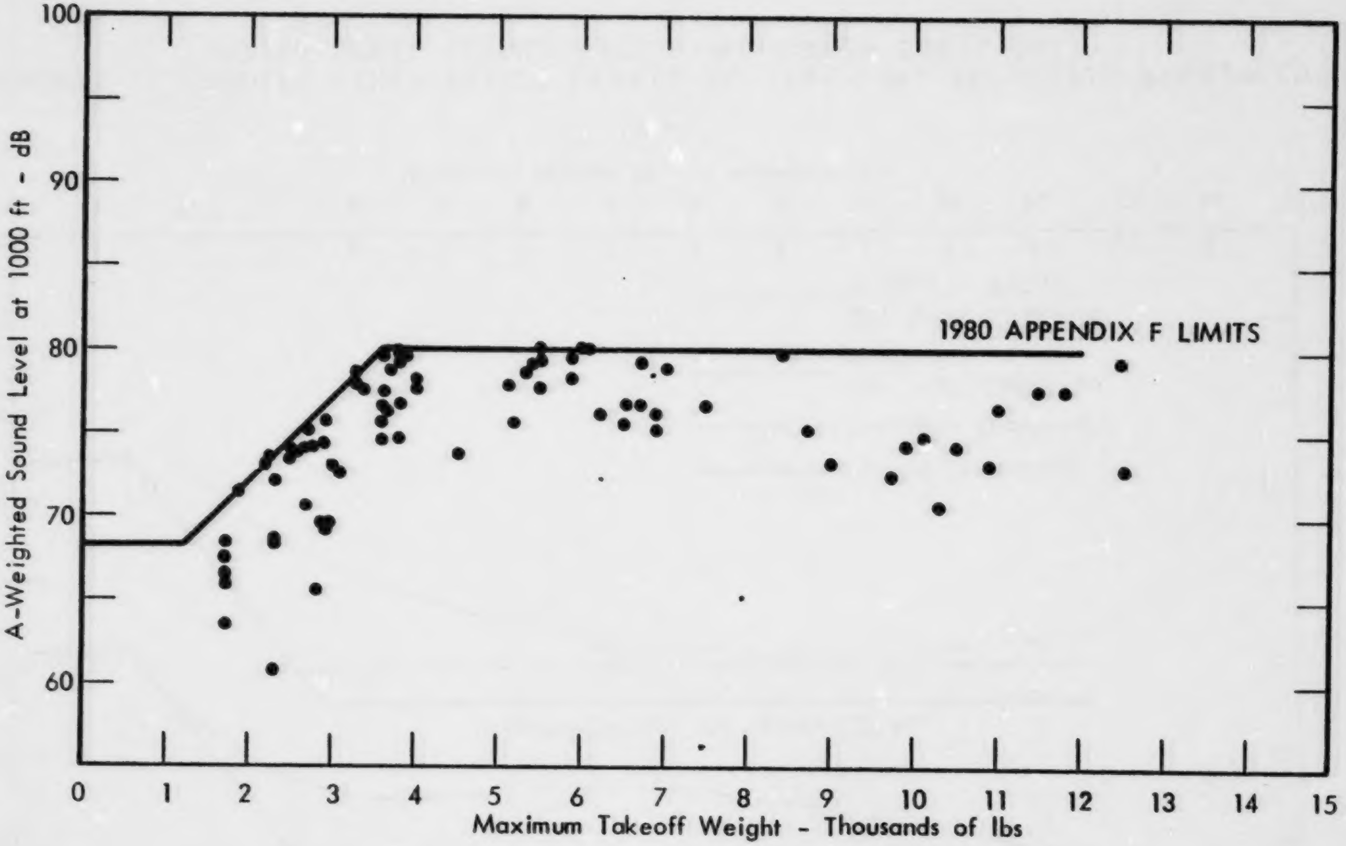

FIGURE 15. MAXIMUM A-WEIGHTED SOUND LEVELS FOR 1980 AIRPLANES - APPENDIX F TESTS

number of airplanes are just barely in compliance, the average airplane sound level is 2 to 5 decibels below the limits. Data for the same airplanes in terms of EPNL are shown in Figure 16 in relation to the three EPA proposed sound level limits. All airplanes comply with the "available" technology proposal. Although airplanes with weights below 4000 pounds are as much as 7 decibels above the "future" technology proposal, all airplanes with weights above 7500 pounds would comply, some with margins of as much as 10 decibels.

3.3.3 Propeller-Driven Small Airplane Sound Levels

The most common comparison of small airplane sound levels uses the Appendix F test conditions, namely the maximum A-weighted sound level (L_{AM}) measured during a flyover at 1000 feet above ground at the "highest power in the normal operating range," adjusted by the performance allowance of Appendix F. The Appendix F levels for the 1980 production fleet are listed in Table 2, along with the performance adjustment calculated from reported performance data. A negative value for the performance adjustment indicates the number of decibels subtracted from the measured sound level to obtain the Appendix F reported sound level. Effective perceived noise levels (L_{EPN}) and A-weighted sound exposure levels (L_{AE}) under the same test conditions have been calculated for each airplane and are also listed in Table 2. These last values were computed from the measured A-weighted sound levels by the following empirical conversions.

$$L_{AE} = L_{AM} + 10 \log_{10} \frac{h}{V} - 2 \qquad (1)$$

$$L_{EPN} = L_{AE} + 22 - 24 M_h \qquad (2)$$

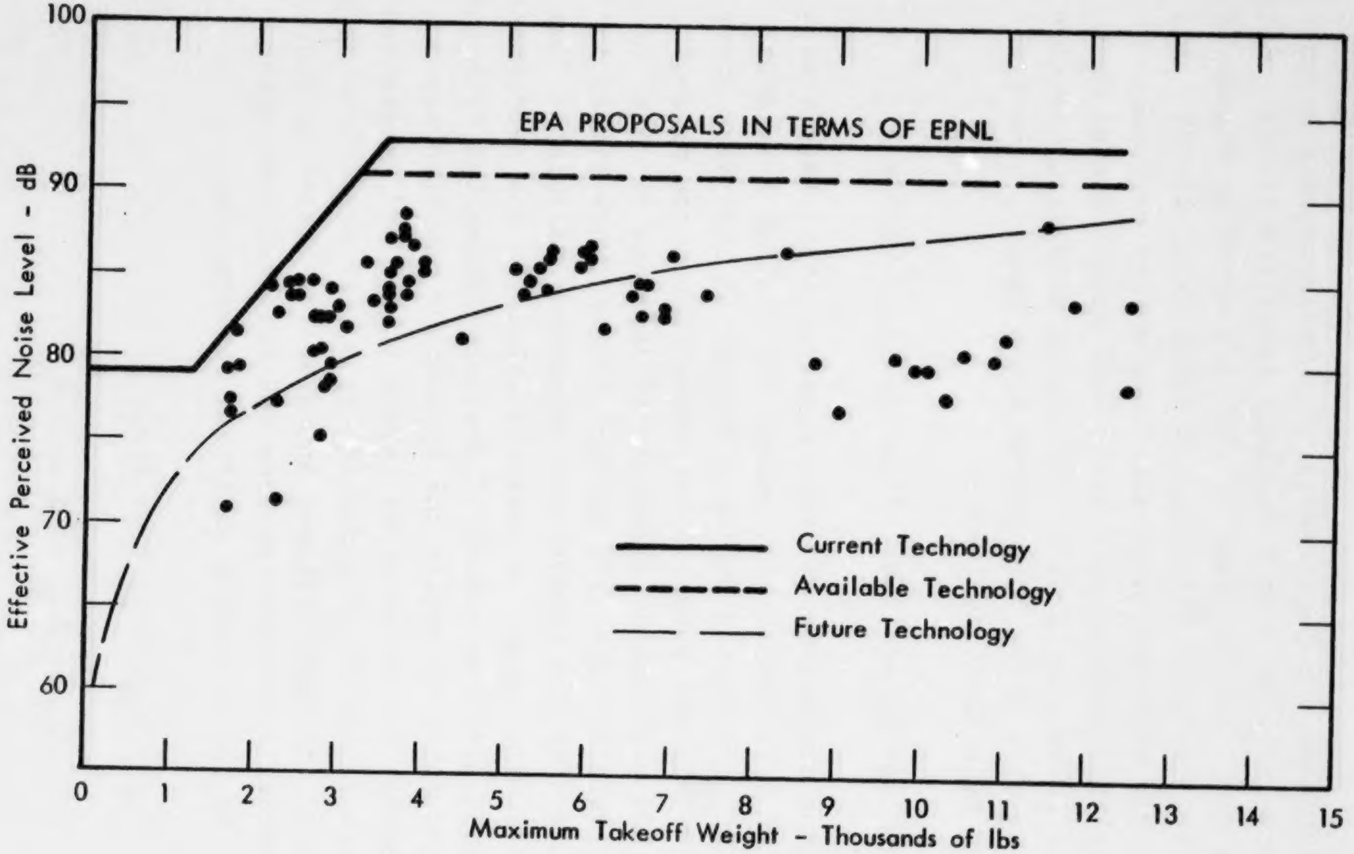

FIGURE 16. EFFECTIVE PERCEIVED NOISE LEVELS FOR 1980 AIRPLANES UNDER APPENDIX F TEST CONDITIONS

TABLE 2

PROPELLER-DRIVEN SMALL AIRPLANES
1980 PRODUCTION FLEET SOUND LEVELS
AT APPENDIX F CONDITIONS (HT = 1000 FT)

Airplane Model		Weight lbs.	Perf. Corr. dB	L_{AM} dB	L_{EPN} dB	L_{AE} dB
BEECH						
Single engine piston						
C23	Sundowner	2450	-0.1	73.3	83.4	81.0
C24R	Sierra	2750	-0.8	70.8	80.1	77.8
F33A/C	Bonanza	3400	-1.4	77.4	83.2	83.2
A36TC	Bonanza Turbo	3650	-0.3	78.6	85.5	84.5
77	Skipper	1675	-1.5	66.4	77.6	74.6
Multiengine piston						
B55	Baron	5100	-3.4	78.0	85.2	83.4
E55	Baron	5300	-3.9	78.5	84.7	83.6
58	Baron	5400	-3.6	79.0	85.3	84.2
58P	Baron-Press.	6200	-1.7	76.1	81.8	80.9
B60	Duke	6775	-1.4	79.2	84.7	84.1
76	Duchess	3900	-2.6	78.7	86.8	84.8
Turboprop						
C90	King Air	9650	-4.1	74.4	80.1	78.9
E90	King Air	10100	-3.9	74.7	79.6	78.8
F90	King Air	10950	(-5.3)*	73.0	80.1	76.9
A100	King Air	11500	-2.7	77.3	88.7	81.3
B100	King Air	11800	-3.4	77.3	83.6	81.0
200	Super King Air	12500	(-5.3)	79.2	83.6	82.7
BELLANCA						
Single engine piston						
7ECA	Citabria	1650	-1.9	68.3	79.7	76.3
8G CBC	Scout	2150	-3.8	77.0	86.4	85.0
8KCAB	Decathlon	1800	-4.3	71.9	81.6	79.3

*Numbers in parentheses are for information. The performance correction included in the different sound levels is limited to -5 dB by FAA Part 36.

TABLE 2 (Cont'd)

Airplane Model		Weight lbs.	Perf. Corr. dB	L_{AM} dB	L_{EPN} dB	L_{AE} dB
CESSNA						
Single Engine Piston						
152	Aerobat	1750	-1.3	66.3	79.5	74.3
172P	Skyhawk	2300	-0.7	73.8	82.9	81.2
R172K	Hawk XP	2550	-1.4	74.1	84.4	81.3
172RG	Cutlass RG	2650	0.3	73.9	82.7	80.8
180K	Skywagon	2800	-3.0	65.8	75.5	72.6
182Q	Skylane	2950	-2.5	69.1	78.7	75.8
TR182	Turbo Skyl.RG	3100	-1.6	72.6	81.7	78.9
A185F	Skywagon	3350	-2.5	77.9	85.3	84.6
U206G	Stationair 6	3600	-0.8	79.4	87.1	85.9
TU206G	Turbo Statn. 6	3600	-1.1	75.4	83.7	81.9
207A	Statn. 8	3800	1.3	79.8	87.6	86.5
T207A	Turbo Statn. 8	3800	-0.1	76.3	84.5	82.6
210N	Centurion	3800	0.3	79.6	86.4	85.5
T210N	Turbo Centurion	4000	0.9	77.4	85.0	83.3
P210N	Press. Centurion	4000	0.9	78.0	85.7	84.0
Multiengine Piston						
310R		5500	-3.3	79.1	86.0	84.5
T310R	Turbo 310R	5500	-3.7	77.7	84.1	83.0
335	Turbo	5990	-1.8	78.1	85.2	83.6
340A	Press.	5990	-3.1	79.7	86.7	85.1
402C	Turbo Businessliner	6850	-1.9	75.1	82.7	80.5
404	Titan Ambassador Turbo	8400	-3.0	78.9	86.4	84.3
414A	Chancellor Turbo Press.	6750	-2.4	76.6	84.4	82.1
421C	Golden Eagle Press.	7450	-4.1	76.7	83.9	81.9
Turboprop						
441	Conquest	9850	-3.9	74.0	79.5	77.3

TABLE 2 (Cont'd)

Airplane Model	Weight lbs.	Perf. Corr. dB	L_{AM} dB	L_{EPN} dB	L_{AE} dB
GULFSTREAM AMERICAN (GRUMMAN)					
Single engine piston					
AA-5A Cheetah	2200	1.3	73.6	84.0	80.9
AA-5B Tiger	2400	-0.4	75.1	84.4	82.0
Multiengine piston					
GA-7 Cougar	3800	-1.6	79.0	88.4	85.5
MAULE					
Single engine piston					
M-5 180 TC	2300	-2.7	76.7	85.3	83.5
M-5 210 TC	2300	(-6.9)	68.7	77.2	74.7
M-5 235C Lun. Rocket	2300	(-7.2)	60.9	71.4	67.6
MITSUBISHI					
Turboprop					
MU-2B-40 Solitaire	10475	-3.3	74.0	80.6	77.0
MOONEY					
201 M20J	2740	-1.5	74.0	82.5	80.1
231 M20K Turbo	2950	-0.7	75.5	84.0	81.6
PIPER (PA-)					
Single engine piston					
18-150 Super Cub	1750	-4.3	65.9	76.9	73.9
28-161 Warrior	2325	0.4	72.0	82.4	79.5
28-181 Archer II	2550	0.02	73.9	83.2	80.9
28RT-201 Arrow IV	2750	0.3	75.1	84.4	82.1
28RT-201T Arrow IV Turbo	2900	0.1	69.4	78.5	75.6
28-236 Dakota	3000	-2.6	72.9	82.9	79.5
28-201T Turbo Dakota	2900	0.2	69.6	79.5	76.4

TABLE 2 (Cont'd)

Airplane Model		Weight lbs.	Perf. Corr. dB	L_{AM} dB	L_{EPN} dB	L_{AE} dB
PIPER (PA-)						
Single engine piston (cont'd)						
32RT-300	Lance	3600	-0.2	85.3	91.8	91.3
32-301	Saratoga	3600	-0.4	76.7	84.0	82.9
32-301T	Turbo Saratoga	3600	-2.9	74.4	82.1	80.9
32R-301	Saratoga SP	3600	-2.1	77.6	85.0	83.0
32R-301T	Turbo Saratoga SP	3600	-1.4	76.1	82.9	82.0
38-112	Tomahawk	1670	-1.5	67.8	71.1	71.0
Multiengine piston						
23-250	Aztec	5200	-3.7	75.7	83.9	81.4
31-310	Navajo C Turbo	6500	-3.8	75.4	82.3	80.7
31-325	Navajo C/R Turbo	6500	-3.0	76.9	83.9	82.3
31-350	Chieftain Turbo	7000	-2.0	78.9	86.0	84.3
34-200T	Seneca II Turbo	4575	-3.5	73.5	81.9	79.2
44-180	Seminole	3800	-2.9	74.7	83.3	80.8
600A	Aerostar	5500	-2.8	80.0	86.2	84.8
601B	Aerostar Turbo	6000	-1.0	80.0	86.4	84.9
601P	Aerostar Pressurized	6000	-0.6	80.0	85.9	84.9
Turboprop						
31T-500T1	Cheyenne I	8700	-1.8	75.0	79.9	79.1
31T-620	Cheyenne II	9000	(-6.5)	73.2	77.0	76.7
42-720	Cheyenne III	11000	-3.8	76.6	81.6	80.1

TABLE 2 (Cont'd)

Airplane Model	Weight lbs.	Perf. Corr. dB	L_{AM} dB	L_{EPN} dB	L_{AE} dB
ROCKWELL INTERNATIONAL					
Single engine piston					
112TC-A Commander	2850	-1.0	74.2	82.6	80.1
114 Commander	3140	-0.8	78.6	86.4	84.7
Multiengine piston					
700 Commander Press.	6947	-1.7	76.0	83.1	81.6
Turboprop					
840 Commander	10325	(-5.8)	71.5	77.9	74.9
SWEARINGEN (SA-)					
Turboprop					
226TB Merlin IIIB	12500	-3.3	72.8	78.5	75.9

where h is height in feet, V is airspeed in knots, and M_h is helical tip Mach number.

Unfortunately, the Appendix F test conditions tell little about the sound levels produced during normal operations around an airport. Compare a normal takeoff and climb with the Appendix F test conditions. Airplanes with fixed-pitch propellers will typically have a maximum rpm of 2600 to 2700 during an Appendix F test, yet usually will develop not much more than 2400 rpm during a typical takeoff climb. Further, climb speed for best rate-of-climb is typically about half to two-thirds of the speed used in Appendix F tests. The combination of these two factors reduces the helical Mach number during climb in such a way that, at 1000 feet, the A-weighted sound levels may be as much as 10 to 12 decibels lower than during an Appendix F test.

A similar situation though not as dramatic, results for airplanes with controllable-pitch propellers. The usual practice is to reduce from takeoff rpm to a climb well before reaching 1000 feet. This reduction is typically 150 to 250 rpm. Again, climb airspeed is a fraction of the Appendix F speed. The combination results in reduced helical tip Mach numbers, with a consequent reduction in A-weighted sound levels of from 4 to 8 decibels relative to the Appendix F levels (without performance adjustment) at the same height.

The use of maximum A-weighted sound levels still requires a duration adjustment if the community noise expressed in day-night average sound level is to be computed. Since this adjustment varies with both the slant distance from an observer to the airplane flight path and airplane speed, no single number translation applies. Considering the large number of individual airplane types involved, in contrast to business jets, it is impractical to develop individual functions of sound exposure level versus slant distance for each prop airplane. Instead a composite SEL/distance function has been derived from a large number of measurements around general aviation airports and is used in Section 5 of this report in the airport analyses.

In order to compare sound levels that are typical of normal prop airplane operations at a GA airport, it is convenient to examine the sound levels at a representative point in a community during takeoff. Since 89 percent of the 12,064 civil airports in the country, as of the end of 1979, have runways of 5000 feet length or less, 6500 feet from brake release (i.e. 1500 from the end of the runway) would be a typical close-in location where one might expect residences to exist. Sound exposure level and EPNL have been computed for each of the airplanes in the 1980 production fleet and are listed in Table 3.

In these calculations it was assumed that the airplane operated at maximum gross weight from a sea level airport on a standard day with no wind. It was also assumed that airplanes with fixed-pitch propellers would climb with full throttle, producing 2400 rpm. Airplanes with controllable pitch propellers were assumed to climb at takeoff power and rpm until reaching a height of 500 feet above ground. At this point rpm and throttle settings were reduced to climb power. In both instances airspeed for best rate-of-climb, V_y, was assumed. The empirical equations used for these calculations are:

$$L_{AE} = 167 + 24 \log_{10}\left(\frac{M_h^{10}}{h}\right) + 10 \log_{10} \frac{Nh}{V_y} + 4b \qquad (3)$$

TABLE 3

PROPELLER-DRIVEN SMALL AIRPLANES
1980 PRODUCTION FLEET SOUND LEVELS AT 6500 FT. FROM BRAKE RELEASE ON TAKEOFF

Airplane Model		L_{EPN} dB	L_{AE} dB
BEECH			
Single engine piston			
C23	Sundowner	81.9	77.2
C24R	Sierra	90.6	88.0
F33A/C	Bonanza	92.1	90.0
A36TC	Bonanza Turbo	95.0	93.6
77	Skipper	76.3	70.6
Multiengine piston			
B55	Baron	92.0	88.7
E55	Baron	91.6	88.3
58	Baron	91.8	88.5
58P	Baron - Press.	99.5	97.6
B60	Duke	101.2	99.8
76	Duchess	90.6	86.6
Turboprop			
C90	King Air	87.7	83.6
E90	King Air	87.5	83.4
F90	King Air	78.0	72.1
A100	King Air	86.6	82.0
B100	King Air	85.5	80.9
200	King Air Super	82.2	77.3
BELLANCA			
Single engine piston			
7ECA	Citabria	75.7	70.1
8G CBC	Scout	83.0	79.2
8KCAB	Decathlon	78.7	73.9

TABLE 3 (Cont'd)

Airplane Model		L_{EPN} dB	L_{AE} dB
CESSNA			
Single engine piston			
152	Aerobat	72.6	66.3
172P	Skyhawk	80.0	75.1
R172K	Hawk XP	83.8	79.8
172RG	Cutlass RG	92.7	90.4
180K	Skywagon	85.0	81.7
182Q	Skylane	85.6	82.2
TR182	Turbo Skyl RG	86.4	83.1
A185F	Skywagon	89.3	86.7
U206G	Stationair 6	88.4	85.3
TU206G	Turbo Station 6	88.0	85.0
207A	Station 8	100.5	100.1
T207A	Turbo Station 8	95.1	93.6
210N	Centurion	100.1	99.7
T210N	Turbo Centurion	96.2	94.7
P210N	Press. Centurion	96.3	94.8
Multiengine piston			
310R		91.0	87.4
T310R	Turbo 310R	91.8	88.4
335	Turbo	91.5	87.8
340A	Press.	90.6	87.0
402C	Turbo Businessliner	91.3	87.7
404	Titan Ambassador Turbo	85.8	81.1
414A	Chancellor Turbo Press.	91.3	87.6
421C	Golden Eagle Press.	85.1	80.4
Turboprop			
441	Conquest	85.5	81.1

TABLE 3 (Cont'd)

Airplane Model		L_{EPN} dB	L_{AE} dB
GULFSTREAM AMERICAN (GRUMMAN)			
Single engine piston			
AA-5A	Cheetah	79.2	73.8
AA-5B	Tiger	80.1	75.3
Multiengine piston			
GA-7	Cougar	87.4	82.8
MAULE			
Single engine piston			
M-5	180 TC	85.0	81.5
M-5	235C Lun. Rocket	78.1	73.8
M-5	210 TC	78.2	73.6
MITSUBISHI			
Turboprop			
MU-2B-40	Solitaire	74.7	68.3
MOONEY			
Single engine piston			
201	M20J	81.4	77.0
231	M20K Turbo	88.6	85.6
PIPER (PA-)			
Single engine piston			
18-150	Super Cub	76.0	70.8
28-161	Warrier	79.7	74.5
28-181	Archer II	82.1	77.4
28RT-201	Arrow IV	91.5	88.9
28RT-201T	Arrow IV Turbo	87.1	83.8
28-236	Dakota	83.3	79.5

TABLE 3 (Cont'd)

Airplane Model PIPER (PA-)		L_{EPN} dB	L_{AE} dB
Single engine piston (cont'd)			
28-201T	Turbo Dakota	87.4	84.0
32-300	Six-300	89.7	87.2
32RT-300	Lance	97.7	96.6
32-301	Saratoga	95.1	93.5
32-301T	Turbo Saratoga	88.1	85.1
32R-301	Saratoga SP	95.3	93.8
32R-301T	Turbo Saratoga SP	94.7	93.2
38-112	Tomahawk	76.5	70.8
Multiengine piston			
23-250T	Turbo Aztec F	90.8	87.2
31-310	Navajo C Turbo	94.2	91.2
31-325	Navajo C/R Turbo	94.7	91.6
31-350	Chieftain Turbo	95.5	92.5
34-200T	Seneca II Turbo	89.6	85.7
44-180	Seminole	88.1	83.8
600A	Aerostar	92.4	89.2
601B	Aerostar Turbo	100.6	98.7
601P	Aerostar Press.	100.9	99.1
Turboprop			
31T-500T	Cheyenne I	97.5	95.1
31T-620	Cheyenne II	85.6	81.6
42-720	Cheyenne III	81.5	76.3

TABLE 3 (Cont'd)

Airplane Model	L_{EPN} dB	L_{AE} dB
ROCKWELL INTERNATIONAL		
Single engine piston		
112TC-A Commander	87.8	84.6
114 Commander	91.6	89.3
Multiengine piston		
700 Commander Press.	96.2	93.6
Turboprop		
840 Commander	78.4	73.0
SWEARINGEN (SA-)		
Turboprop		
226TB Merlin IIIB	82.0	76.8

$$L_{EPN} = L_{AE} + 22 - 24\ M_h \qquad (4)$$

where M_h is helical tip Mach number, N is number of engines, h is height in feet, V_y is airspeed in knots, and b is equal to 1 for cutdown propellers and 0 for standard, uncut propellers.

A similar set of calculations was performed for older airplanes to represent the 1975 baseline fleet. For these calculations various models of the same airplane series were aggregated to obtain an average representation of the whole series. These data are listed in Table 4.

3.3.4 Propeller-Driven Airplane Operating Procedures

3.3.4.1 Approach

Most GA operations are conducted under visual flight rules (VFR) and weather restrictions. Under these conditions most single-engine airplanes use a steeper flight path than is customary when using an instrument landing system. Observations at a number of airports indicate that approaches at glide-path angles of 5 to 7 degrees are most common. A 5 degree approach angle is assumed in the analyses of this report for single-engine airplanes.

Twin-engine airplanes generally use a flatter approach angle than single-engine airplanes, even when flying VFR. This angle approach is comparable to a normal 3 degree glide-path of an instrument landing system. A 3 degree approach angle is assumed for twin-engine airplanes in these analyses.

TABLE 4

PROPELLER-DRIVEN SMALL AIRCRAFT 1975 BASE FLEET SOUND LEVELS AT 6500 FT FROM BRAKE RELEASE ON TAKEOFF

Airplane Model		L_{EPN}	L_{AE}
BEECH			
Single engine piston			
23	series	81.9	77.2
35	series	92.0	89.9
35-33	series	92.2	90.1
36	series	95.0	93.6
Multiengine piston			
55	series	92.0	88.7
B60	Duke	101.2	99.8
B80	series 65	99.6	97.6
Turboprop			
90 & 100	series	85.5	80.9
BELLANCA			
Single engine piston			
7GCAA	Citabria	72.8	67.1
7&8 GCBC	Scout	83.0	79.2
300	Super Viking	87.7	84.7

TABLE 4 (Cont'd)

Airplane Model		L_{EPN}	L_{AE}
CESSNA			
Single engine piston			
150	series	73.1	66.7
170	series	82.3	77.6
172	series up to 172N	79.9	75.0
177	series	93.0	91.0
180	series up to 180K	88.7	86.1
182	series up to 182P	89.4	86.9
185	series up to A185F	95.2	94.1
206 & 207	series	95.1	93.6
210	series up to 210P	95.0	93.5
Multiengine piston			
310	series	91.0	87.4
320	series	94.5	91.9
337	series	103.5	102.3
340	series	90.6	87.0
401	series	90.7	87.0
421	series	85.1	80.4
GULFSTREAM AMERICAN (GRUMMAN)			
AA	series	79.2	73.8
MAULE			
Single engine piston			
M-4 & 5 series		80.9	77.0

TABLE 4 Cont'd)

Airplane Model	L_{EPN}	L_{AE}
MITSUBISHI		
Turboprop		
MU series	87.1	83.0
MOONEY		
M20 series	81.4	77.0
PIPER (PA-)		
Single engine piston		
18 series	76.0	70.8
24 series	84.4	80.7
28 series	87.1	83.7
32 series	89.7	87.2
Multiengine piston		
23 series	90.8	87.2
30 series	85.7	80.9
31 series	94.2	91.2
34 series	89.6	85.7
600 series	92.4	89.2
Turboprop		
31T series	85.6	81.6
ROCKWELL INTERNATIONAL		
Single engine piston		
112 & 114 series	91.6	89.3
Multiengine piston		
500 & 600 series	101.0	99.4
Turboprop		
690 series	78.9	73.4

TABLE 4 (Cont'd)

Airplane Model		L_{EPN}	L_{AE}
SWEARINGEN			
Turboprop			
226	series	92.3	89.4

Airspeeds for final approach paths in these analyses are assumed to be 1.3 times the airplane stall speed in landing configuration. Approach powers assumed are 0.2 times maximum rated power for single-engine airplanes and 0.3 times maximum rated power for twin-engine airplanes.

3.3.4.2 Takeoff

As in the case of business jets, there is a wide variation in the takeoff and climb capability of prop airplanes. Composite takeoff profiles have been developed for single and twin-engined airplanes, as shown in Figure 11 on page 3-19. These profiles, along with the composite SEL versus distance function used in Section 5 of this report, provide long-term average SEL values that have been measured at a number of general aviation airports.

4.0 FORECASTS OF FLEET COMPOSITION, FLIGHT OPERATIONS, AND SOUND LEVELS

The purpose of the study described in this report is to examine GA noise around airports in 5 year intervals from 1975 until 2000. The obviously most difficult feature of forecasting is to estimate the number of airplanes that will enter the GA fleet during these times. Although the long-term trend of GA fleet growth over the past two decades has remained quite stable, the rapid increase in fuel costs and inflation over the past few years will undoubtedly make forecasts of at least the small propeller-driven airplanes extremely speculative.

The forecasts for growth of the business jet and turboprop fleets are likely to be much more reliable, since their growth has been essentially immune from the economic factors in recent years. The effects of airline deregulation on restrictions of service to many airports, rapid increases in airline travel costs, greatly improved fuel efficiency of new jets and turboprops, the cash value of personal time, and the lengthening backlog and delivery times for new airplanes all point to high rates of growth of jet and turboprop airplanes for business use.

A troublesome factor in projecting future flight operations is the negative rate of growth of available airports. Despite the over 4 billion dollars accumulated in the Airways and Airports Trust Fund, the spotty availability of these federal funds for airport development has not counteracted the decrease in the number of public use airports. The number of GA airports available for public use has decreased from 5992 in 1972 to 5501 at the beginning of 1980. A net loss of 216 airports took place between 1975 and 1980.

4.1 General Aviation Fleet Forecasts

FAA has, among its other major functions, the responsibility of providing aircraft flight operational services to the nation in terms of air traffic control for both selected airports and for IFR en route flights. Additional flight services include pilot briefings and other communication services. The FAA also has the responsibility for developing the national airport system plan (NASP)8/ and supporting individual airport plans, as well as airport construction and facility improvements. In order to project the demand for these services, FAA has developed a number of econometric models. General Aviation forecasts9/ utilize a number of economic and demographic variables to derive various measures of activity such as number of aircraft and the level of their expected operations. Time series analyses of historical trends are used to estimate hours flown per aircraft type and number of operations per aircraft.

The major economic variables used to generate the 1980-1991 FAA forecast of the overall size of the GA fleet and the hours flown are listed in Table 5. Three levels of growth are stated: a baseline assumption, one of rapid growth, and a third of "stagflation" (limited growth influenced by high inflationary growth). In order to better visualize the trends in the data, and to extrapolate the FAA forecast to 1995 and 2000, the compound growth rate percentages between successive 5 year intervals have been calculated. These rates are indicated by the smaller figures between the various column entries for specific years. For example, the baseline growth in GNP from 1980 to 1985 is forecast to increase from 1483 to 1726 billion dollars. The compound growth rate is 3.1 percent per year.

TABLE 5

GENERAL ECONOMIC INDICATORS
FAA - 1979 FORECAST FY 1980-1991

Base Year: 1972
1972 dollars

	1975	1980		1985		1990		1995		2000
"Rapid growth"			4.7	1869	4.9	2374				
GNP "Baseline"		1483	3.1	1726	2.8	1979				
"Stagflation" (billions of 1972 dollars)			2.7	1698	2.1	1886				
Employment (millions)			2.0	109.7	1.8	119.7				
		99.4	1.5	107.0	1.2	113.6				
			4.1	103.5	0.7	107.4				
CPI (index = 100 for 1972)			5.4	327	4.9	415				
		251	6.4	343	5.4	446				
			7.0	352	7.1	495				
Disposable Personal Income (billions of 1972 dollars)			4.8	1292	5.7	1706				
		1023	2.7	1171	2.8	1342				
			1.8	1121	1.6	1213				
Oil & Gas Deflator (index = 100 for 1972)			2.2	327	9.0	503				
		293	9.2	454	5.6	597				
			8.6	443	7.8	644				
Result										
GA Fleet (Total including helicopters & balloons) (thousands)			5.1	274	3.5	325	3.5	386	3.5	458
		214	4.5	267	2.6	304	2.4	342	1.8	374
			3.3	252	1.2	267	1.0	281	0.8	292
Hours Flown (millions)			6.5	60.0	3.1	70.0	3.1	81.5	3.1	96.8
		43.8	4.5	54.6	3.2	64.0	2.6	72.8	2.0	80.4
			1.2	46.4	3.2	54.4	2.2	55.6	1.0	58.4
U.S. Population	212.7	220.7		229.7		236.3		242.3		245.9
Ratio to 1975		1.038		1.080		1.111		1.139		1.156

Estimates of the GA fleet size in the years 1995 and 2000 are not provided in the FAA forecast. The values for these years were estimated by the authors of this report based on the growth rate percentages shown in Table 5. These rates were estimated from the trends of the previous 5 year intervals, influenced somewhat by the 1977 U.S. Census Bureau estimates of total U.S. population. These values are also shown in Table 5. The particular estimates listed are from the Census Bureau Series 3 projection as listed in Reference 9.

The FAA forecast also provides a year-by-year estimate of the number of active GA airplanes by general class of aircraft, as well as the hours flown, until fiscal year 1991. These values are listed in Table 6, with extrapolations to 1995 and 2000 on the basis of the compound annual growth rates indicated by the small figures between the major columns. There are small differences between the values listed here and in the FAA forecast. The FAA forecast is based on fiscal years. The current study is keyed to calendar years. Calendar year data were obtained by linear interpolation of the FAA fiscal year data.

4.2 Business Jet Fleet Forecast

The rapid growth rate of the business jet fleet will also be accompanied by a substantial reduction in fleet average sound levels. Since business jets, in 1975, were the largest source of community noise around GA airports, changes in fleet composition will make significant changes in community noise. In order to assess the changes in fleet sound levels with time a detailed forecast of the business jet fleet by specific airplane (or engine) type is required.

TABLE 6
GENERAL AVIATION FORECAST

	End of Calendar Year										
	1975		1980		1985		1990		1995		2000
Active Airplanes (x10³)											
Single engine-piston	136.6	4.6	170.8	4.3	210.4	2.4	236.4	1.9	259.7	1.3	277.0
Twin engine-piston	20.3	5.2	26.2	4.8	33.1	2.8	38.0	2.2	42.4	1.6	45.9
Turboprop	2.5	9.3	3.9	7.5	5.6	6.6	7.7	5.8	10.2	4.7	12.8
Jet	1.7	13.5	3.2	8.0	4.7	6.4	6.4	5.1	8.2	4.1	10.0
Total	161.1	4.8	204.1	4.5	253.8	2.6	288.5	2.1	320.5	1.5	345.7
Rapid growth				4.9		3.5		3.5		3.5	
Stagflation				3.7		1.2		0.9		0.7	
Hours flown - (x10⁶)											
Single engine-piston	23.0	3.9	27.9	4.8	35.2	2.7	40.3	2.1	44.7	1.4	47.9
Twin engine-piston	5.3	4.8	6.7	6.3	9.1	3.5	10.8	2.8	12.4	2.0	13.7
Turboprop	1.4	8.4	2.1	6.7	2.9	6.6	4.0	5.8	5.3	4.7	6.7
Jet	0.9	13.6	1.7	7.1	2.4	7.2	3.4	5.7	4.5	4.6	5.6
Total	30.6	4.6	38.4	5.3	49.6	3.4	58.5	2.7	66.9	2.0	73.9
Rapid growth				6.8		3.4		3.2		3.0	
Stagflation				3.5		3.2		2.2		1.0	

The numbers of business jets of less than 75,000 pounds gross weight existing in the active U.S. fleet in 1975 and projected to 1990 are listed in Table 7 by airplane type. These were generated on the basis of several considerations. First, the actual number in the years 1975 and 1978 were obtained from FAA census data of registered aircraft. The numbers in 1979 and 1980 were estimated from the 1978 census and manufacturers production reports. The total number in each year is less than the FAA jet fleet size listed in Table 6, which includes a variety of military airplanes and larger jets not considered in this study. The 1985 and 1990 fleet compositions were estimated from the 1980 numbers, production plans, the fraction of FAA total jets represented by these business jets, and historical data on market share represented by different airplane models.

The uncertainty in projections to 1995 and 2000 of existing designs and new designs was considered too great to warrant the detail used in the earlier years. Instead, it was estimated that the structure of the fleet would consist of airplanes using turbofan engines in the 2500, 3700, 7500, and 10,000 pound thrust classes for 1975, with the 10,000 pound class dropping out in 2000. The acoustical characteristics of the JT15, TFE731, ALF502, and Spey engines were used to represent these engines. It was assumed that fuel prices would drive all aircraft with straight turbojet engines out of the fleet, either by conversion to turbofans or to scrap, by 1990. On this basis, the 1995 and 2000 fleets were estimated to consist of various fractions powered by one of the turbofan engine classes. Since the acoustical properties of these engines are converging to quite similar sound levels, fleet average noise levels estimated in this fashion are likely to be relatively insensitive to small variations in fractions of the fleet allocated to each engine class.

TABLE 7
BUSINESS JET FLEET COMPOSITION
AT END OF CALENDAR YEAR

Airplane	1975	1980	1985	1990
Cessna Citation I & II	147	577	856	1285
Commander 1121/23	145	143	100	0
Falcon 10	17	123	293	440
Falcon 20	193	215	210	205
Gulfstream II	133	195	195	140
Gulfstream III		12	125	225
Hansa 320	12	16	10	0
HS 125-400/600	152	185	0	0
HS 125-700		27	160	200
Jetstar I	119	80	25	0
Jetstar II		74	130	100
Learjet 23	73	68	0	0
Learjet 24	151	200	150	0
Learjet 25, 28, 29	129	236	175	0
Learjet 35/36	5	288	523	840
M-S Paris		11	8	0
Sabreliner 40	115	115	80	0
Sabreliner 60/70	90	123	85	0
Sabreliner 75A	23	55	55	50
Sabreliner 65A		26	75	75
Westwind 1124		64	94	100
Challenger 600		6	160	380
Citation III			185	420
Corvette SN601		12	12	8
Falcon 50		6	100	200
Learjet 50 Series			121	350
Sabreliner 40/60 conversion			100	100
New designs			153	582
Total	1504	2857	4180	5700

Composite SEL versus distance functions for use in GA airport community noise analyses are derived from "energy" averages of the SEL at a number of constant slant distances, weighted by the fraction of the total fleet represented by the SEL at that distance. Thus the fraction of the total fleet represented by each airplane type is required. These fractions are listed in Table 8 as percentages of the total fleet.

4.3 Business Jet Composite Sound Levels

In this study it is assumed that the long term average community noise produced by GA jet operations at an airport results from operations that are weighted in proportion to the fraction of the total business jet fleet represented by each airplane type. (An exception is discussed in Section 5 of this report.) This assumption is implemented in airport analyses by use of SEL versus slant distance functions that represent a composite SEL for the fleet. The contribution of each airplane type to the composite is a combination of the SEL for the airplane, weighted by the fraction of the fleet it represents.

The composite SEL versus slant distance function is computed by calculating the composite SEL, $L_{AE}(x)$, at a number of individual slant distances, x, from the following expression:

$$\overline{L_{AE}}(x) = 10 \log_{10} \sum_{i=1}^{n} f_i \, 10^{0.1 L_{AEi}(x)} \qquad (5)$$

where f_i is the fraction of the fleet represented by airplanes of the i-th type, and $L_{AEi}(x)$ is the SEL value of slant distance x for the i-th airplane type. The SEL functions for individual airplane/engine types are shown in Figures 2 to 9 in Section 3 of this report. The fleet fractions by airplane type are listed in Table 8. Results of the computations for each 5 year interval from 1975 to 2000 are shown in Figure 17. The composite SEL versus distance function for the current small propeller-driven airplane fleet is also shown in Figure 17 for comparison.

4.4 Propeller-Driven Airplane Forecast

The large size and diversity of the small prop fleet does not lend itself to the detailed analysis used for business jets. Further, there is little need to make such an analysis. The large size of the existing fleet, 159,000 in 1975, 200,000 in 1980, will totally dominate fleet average sound levels for the next two decades, irrespective of the introduction of new airplane models. That is, if all small prop airplanes entering the fleet between 1980 and 2000 were 10 decibels lower than the present fleet average, the fleet average in 2000 would decrease by less than one decibel!

In order to present a conservative picture, e.g. least optimistic, fleet average SEL versus distance function for the current small propeller-driven airplane fleet is used for each analysis period in this study. This function is shown in Figure 17.

The size of the small prop fleet for the different 5 year intervals from 1975 to 2000 is listed in Table 6, based on the FAA forecast to 1990, and the extrapolation to 2000. These fleet sizes are assumed in the airport analyses of this report.

TABLE 8

BUSINESS JET FLEET PROJECTIONS
FRACTION BY AIRCRAFT MODEL

Airplane	Percent of Total					
	1975	1980	1985	1990	1995*	2000*
Citation I & II	9.76	20.21	20.48	22.54	35	35
Commander 1121/1123	9.63	5.01	2.39			
Falcon 10	1.13	4.31	7.01	7.72		
Falcon 20	12.82	7.53	5.02	3.60		
Gulfstream II	8.83	6.83	4.67	2.46		
Gulfstream III		0.39	2.99	3.95	4	0
Hansa 320	0.80	0.56	0.24			
HS-125-400/600	10.11	6.48				
HS-125-700		0.95	3.83	3.51		
Jetstar I	7.91	2.80	0.60			
Jetstar II		2.59	3.11	1.75		
Learjet 23	4.85	2.38				
Learjet 24	10.03	7.00	3.59			
Learjet 25-29	8.57	8.26	4.19			
Learjet 35/36	0.33	10.08	12.51	14.74	41	40
M-S Paris	0.73	0.39	0.19			
Sabreliner 40	7.65	4.03	1.91			
Sabreliner 60/70	5.97	4.31	2.03			
Sabreliner 65A		0.91	1.79	1.32		
Sabreliner 75A	1.53	1.93	1.32	0.88		
Westwind 1124		2.24	2.25	1.75		
Challenger 600		0.21	3.83	6.67	20	25
Citation III			4.43	7.37		
Corvette SN601			0.29	0.14		
Falcon 50			2.39	3.51		
Learjet 50			2.89	6.14		
Sabre/HS conversions			2.39	1.75		
New designs			4.14	10.21		
Total	1504	2857	4180	5700	7300	8925

*1995 and 2000 forecasts are by engine type only. The specific airplanes identified are considered generic of the engine type.

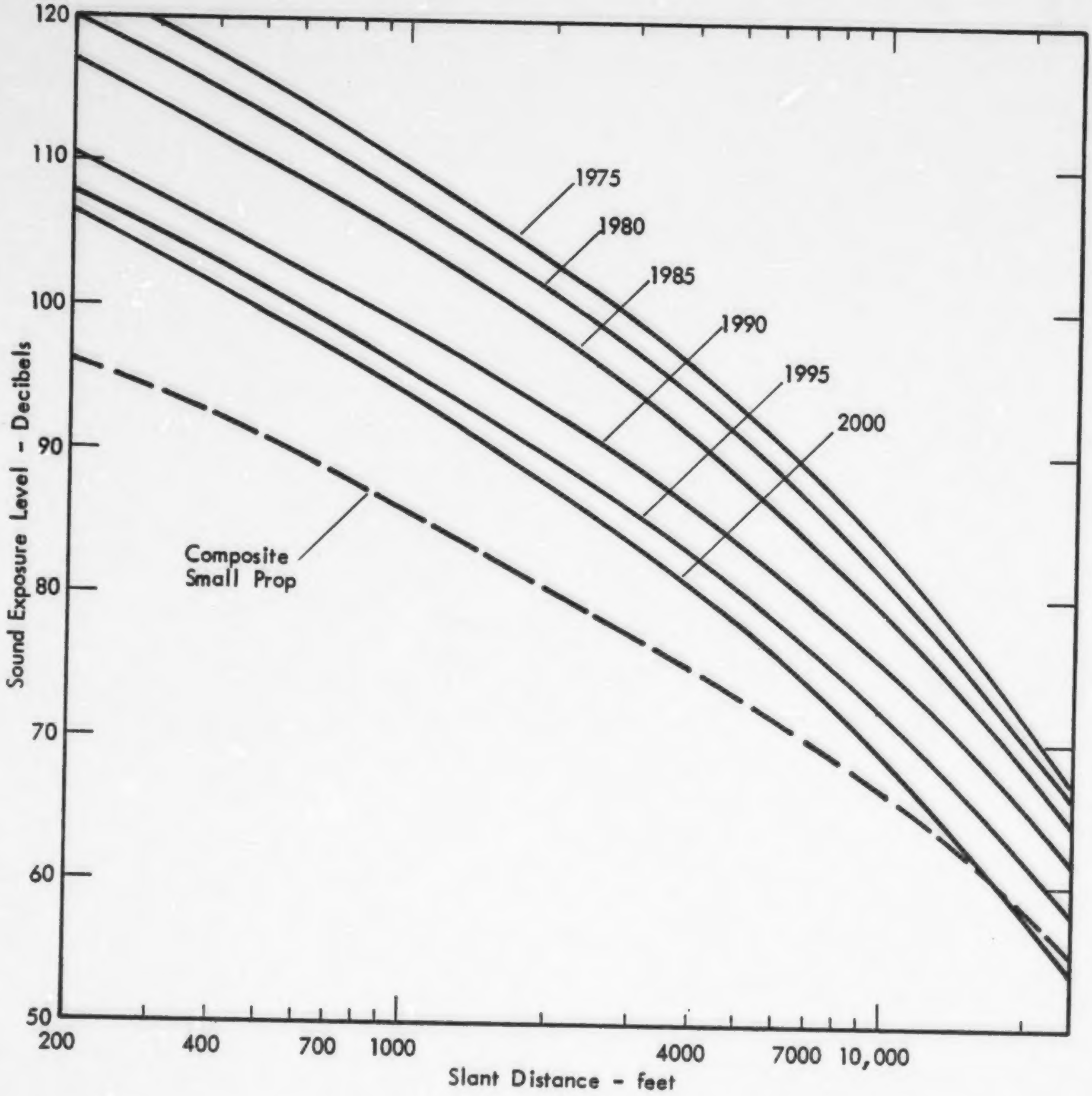

FIGURE 17. SOUND EXPOSURE LEVELS AS A FUNCTION OF SLANT DISTANCE - COMPOSITE BUSINESS JETS FOR YEARS 1975 TO 2000 - TAKEOFF THRUST AND SMALL PROPELLER-DRIVEN AIRPLANES AT TAKEOFF POWER

5.0 AIRPORT CLASSIFICATION AND MODELS FOR COMMUNITY NOISE

5.1 General Considerations

General aviation airports vary in size and number of flight operations from short unpaved dirt strips--remote from any habitation--used infrequently by only the smallest prop airplanes, to full facility airports--completely surrounded by residences--with more than 1500 operations per day. In order to estimate the nature of community noise in the vicinity of GA airports on a national basis, it is necessary to classify airports into sizes, number of operations, mix of airplanes, and geographic dispositions of the airports relative to their immediate inhabited areas.

A starting point in classification of airports for use in noise analyses is to use the same classifications used by FAA in the development of National Airport System Plans[8/]. This classification segregates airports into basic airport roles, in terms of the available runway length, hence the kind of fleet the airport is intended to accommodate; and the level of service the airport is expected to provide.

As far as general aviation airports are concerned, four basic airport roles are defined: basic utility (BU), general utility (GU), basic transport (BT), and general transport (GT). Basic utility airports have runway lengths (for 500 foot elevations) of 3200 feet or less and are intended to be capable of serving 95 percent of the small prop fleet. General utility airports have runway lengths of 4300 feet or less, and should accommodate essentially all small prop airplanes. Basic transport airports are intended to be suitable for business jets having weights of less than 60,000 pounds, while general transport airports can accommodate airplanes of at least 175,000 pounds.

The level of service provided by an airport is defined by four categories: air carrier, commuter service, reliever, and general aviation. Designation of an airport to be in one of these categories is a function of a number of entry criteria for inclusion of the airport in NASP. This classification system also establishes the kind of support the airport is eligible for from federal funds. For the purposes of this study, this classification is used only to exclude air carrier airports from the analyses. Reliever airports are a specific kind of GA airport, and are included in the study as such. Commuter service airports are actually a special class of air carrier airport, but by the nature of their service use airplanes that generally have similar performance and noise characteristics to the turboprops in the small prop fleet. For this reason they were included in the overall category of general aviation airports for the purposes of this study.

Airports, whether publicly or privately owned, are also segregated into those available for public use and those that are restricted to private use. According to an FAA study of general aviation activity[10/], 93 percent of GA operations take place at public use airports. A little over half of the more than 12,000 civil airports in the country are available for public use. On a national basis, the community noise produced at an average private use airport should not be significant, and is not considered in this study.

5.2 Distribution of Airports by Size and Airport Role

There are two basic reasons in this study for classifying airports by airport size and role. Airport size, or more specifically runway length, determines the types of airplanes that can operate from an airport. Secondly, airport role influences the number of daily operations that typically occur at an airport.

Business jets are restricted by regulation to operate only from airports that have minimum runway lengths that are determined primarily by specific airplane performance, operating weight, air temperature, and runway elevation. The runway length required differs for takeoff and landing, but manufacturers provide a single number called balanced field length (BFL) which takes both landing and takeoff distances into consideration. Balanced field lengths for sea level, standard day operation at maximum takeoff weight are listed in Table 1 on page 3-5 for various business jets.

According to these data, only Citations can operate from a basic utility airport with a runway length of 3200 feet or less. Although it is conceivable that other airplanes might be able to off-load sufficiently to use such short runways, it is not plausible that they would. At the general utility airport size of 4300 feet or less, it would be possible to operate the lightest weight LearJets, but it is highly unlikely that many pilots would choose to do so. In practice, then, it would appear that essentially all business jets, with the possible exception of the Citation, operate from airports whose role is defined as either basic or general transport. For community noise analyses, it is assumed in this study that operations at utility airports are performed only by small prop airplanes. Operations at general utility airports may include some Citations, but are dominated by small props. Operations at transport airports include both jets and small props. For the purpose of this study basic and general transport airports are treated as a single category.

The distribution of airports by the length of the longest runway, as of the beginning of 1980, is shown in Figure 18. These data do not provide segregation by public or private use, or by airport role. It is reasonable to assume, however, that the bulk of the airports with long runways are air carrier airports.

More insight is provided on airport size distributions in NASP. Excluding seaplane facilities, heliports, and air carrier airports, there are 2484 airports included in NASP that are considered in this study to be general aviation airports. The fractions of airports by airport role, and hence size, are:

Basic utility	0.58
General utility	0.25
Transport	0.17

5.3 Level of Operations as a Function of Airport Role

Actual traffic counts of operations on a routine basis are kept by FAA only at airports where control towers are in operation. In 1978 the number of airports with towers was 428, with less than 100 at airports that were not part of the air carrier system. Through special studies and reports from individual

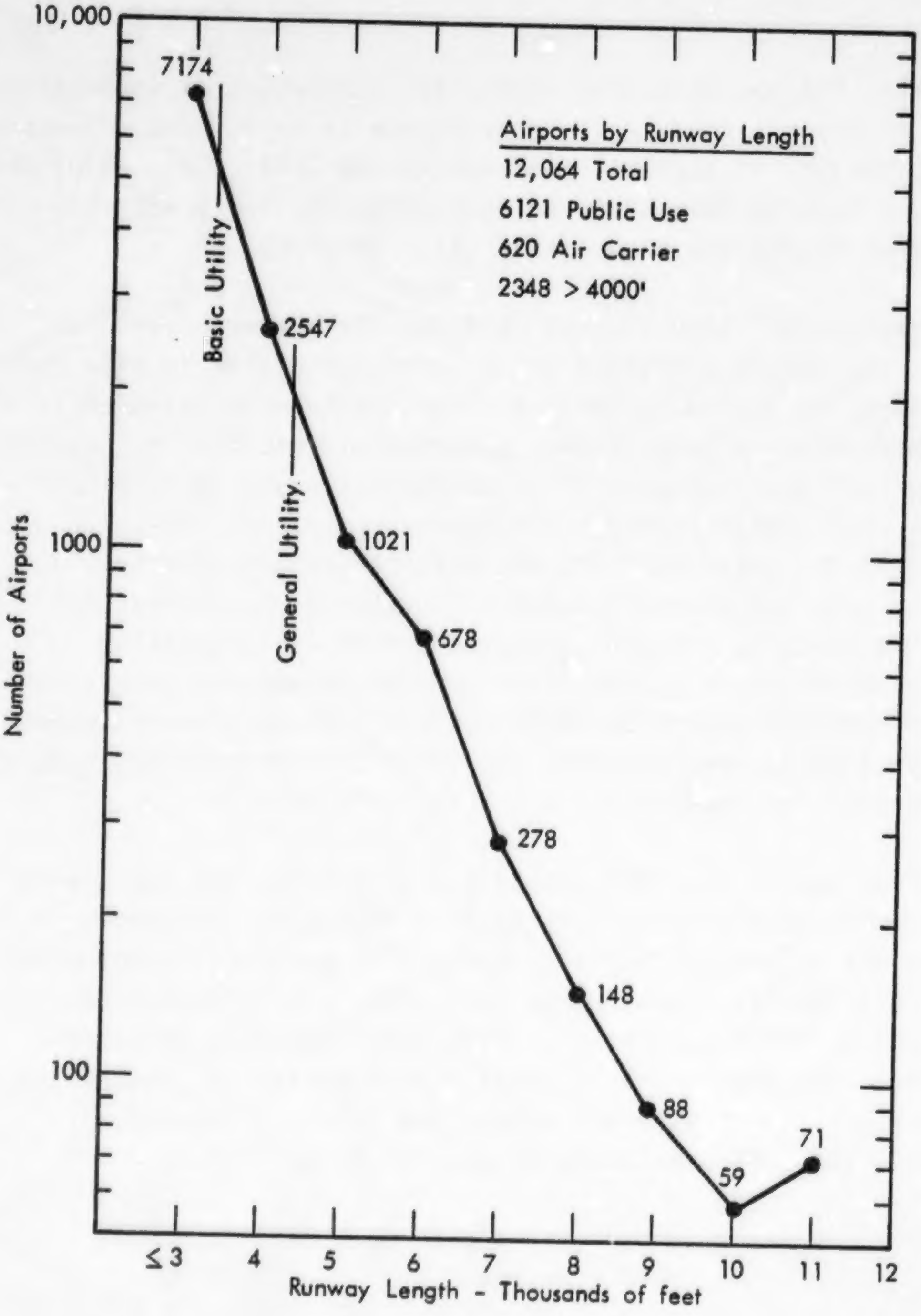

FIGURE 18. U.S. CIVIL AIRPORTS
JANUARY 1, 1980

airports, FAA has developed models for prediction of operations at GA airports. One use of these models is to develop forecasts for operations at airports included in the NASP. This information has been used in this study to develop models for predicting the number of operations at different size airports.

A subset of NASP airports was used for the analyses reported here. The sample consisted of all airports listed in NASP for 10 states, as listed in Table 9. The states were selected to be representative of different geographic regions of the country, having different demographic characteristics and weather conditions. The states selected contain approximately one-third of the airports listed in NASP, and account for approximately one-third of the registered airplanes. Excluding heliports, seaplane facilities, and air carrier airports, the remaining general aviation, reliever, and commuter service airports total 778 of the 2484 listed in NASP. Seven of these airports were projected to be new airports, for which little operational data were available, leaving 771 suitable for analysis.

The first use of the NASP sample was to examine the importance of a number of variables that might *a priori* be considered to affect the number of flight operations at airports, considering basic utility (BU), general utility (GU), and transport (T) airports as separate classes. Five variables were considered in three step-wise multiple regression analyses to predict the sixth variable: total, itinerant, and local operations, respectively. The variables considered were:

y = thousands of operations per year
x_1 = number of based airplanes

TABLE 9

EXTRACT FROM
NATIONAL AIRPORT SYSTEM PLAN (NASP) 1978-1987
FEDERAL AVIATION ADMINISTRATION

State	Population		Registered GA Airplanes		Airports			
	Rank	Den./ SM	Number	Rank	Total	Total Public Use	Total GA Public Use	GA/R/CS in NASP
Alabama	21	72	2422	27	139	111	102	52
California	1	138	21290	1	797	343	317	163
Illinois	5	201	6902	4	855	156	143	65
Iowa	25	51	3004	24	249	180	171	67
Massachusetts	10	743	2450	26	141	61	55	25
Montana	43	5	1804	34	171	144	129	52
New York	2	378	15842	8	485	230	217	69
Oregon	30	24	3488	18	287	123	115	46
Pennsylvania	4	264	5342	9	648	213	205	66
Texas	3	48	12603	2	1234	511	490	173
Sample totals (1977)			65147		5006	2072	1944	778
USA Total 1980 (active) 1975			204100 161100		12064	6121 6437	5501 5817	2484

Number of airplanes based at NASP airports	Aircarrier GA/R/CS	36000 97000
Number of airports in NASP by airport role - excluding air carrier	Basic utility Gen. utility Basic transp. Gen. transport	1434 625 374 51

x_2 = population of principal community served by airport
x_3 = number of airplanes in state per 10,000 population
x_4 = number of airports in state per 10,000 population
x_5 = population density in state per square statute mile

The results of these analyses are listed in Table 10 for total operations, Table 11 for local operations, and Table 12 for itinerant operations. These tables list the multiple correlation coefficient, R, obtained by successive inclusion of each variable in the analysis, the square of the correlation coefficient or the coefficient of determination, R^2, which is the proportion of variance accounted for; the increment in R^2, ΔR^2, obtained by successive inclusion of variables; and the simple correlation coefficient (r) between each independent variable by itself and the dependent variable, y, the number of operations.

Inspection of the tables indicates that in almost all cases using the number of based airplanes to predict number of operations accounted for almost all the variance in the analyses, thus inclusion of the remaining variables provided little improvements. The regression equations using this single independent variable, number of based airplanes, are listed for each case in the tables, along with the standard error in prediction, s_e.

In later analyses, the number of airplanes based at an airport is used to infer the number of operations. This is important to note because the noise produced in an airport vicinity is essentially a function of the number of operations. In the development of a national estimate of community noise, the number of airports for various levels of operations is also used. Figures 19, 20, and 21 show frequency polygons of the number of airports having different numbers of based airplanes for the basic utility,

TABLE 10

MULTIPLE REGRESSIONS
TOTAL OPERATIONS

	Variable	Multiple R	R^2	ΔR^2	Simple r
All Airports	x_1	.87754	.77007	.77007	.87754
	x_2	.87947	.77347	.00339	.65928
	x_3	.88101	.77619	.00272	-.12684
	x_4	.88161	.77723	.00105	-.22240
	x_5	.88557	.78424	.00701	.17749
		$y_{(1000)} = 10.26 + 0.5171x_1$		$s_e = 1.02$	
Basic Utility	x_1	.88843	.78931	.78931	.88843
	x_2	.88929	.79084	.00153	.56478
	x_3	.88953	.79127	.00043	-.14105
	x_4	.88994	.79199	.00072	-.23905
	x_5	.89039	.79368	.00169	.18714
		$y_{(1000)} = 5.55 \text{ x } 0.4725x_1$		$s_e = 0.68$	
General Utility	x_1	.79540	.63266	.63265	.79540
	x_2	.81322	.66133	.02866	.57194
	x_3	.81657	.66679	.00547	-.13503
	x_4	.82119	.67435	.00758	.04889
	x_5	.82549	.68143	.00705	.06638
		$y_{(1000)} = 11.22 + 0.5098x_1$		$s_e = 2.14$	
Basic & General Transport	x_1	.89528	.80153	.80153	.89528
	x_2	.89552	.80195	.00042	.70320
	x_3	.89876	.80776	.00581	.02702
	x_4	.89893	.80808	.00031	-.17086
	x_5	.91146	.83076	.02268	.18540
		$y_{(1000)} = 34.62 + 0.4805x_1$		$s_e = 4.42$	

TABLE 11

MULTIPLE REGRESSIONS
LOCAL OPERATIONS

	Variable	Multiple R	R^2	ΔR^2	Simple r
All Airports	x_1	.79303	.62890	.02890	.79303
	x_2	.79596	.63356	.00466	.61695
	x_3	.80174	.64278	.00922	.16929
	x_4	.80179	.64287	.00009	-.23100
	x_5	.80943	.65518	.01231	.22772
		$y_{(1000)} = 7.29 + 0.2581x_1$		$s_e = 0.71$	
Basic Utility	x_1	.81669	.66698	.66698	.81669
	x_2	.81676	.66710	.00012	.49840
	x_3	.82181	.67537	.00827	-.20881
	x_4	.82393	.67887	.00350	-.25032
	x_5	.82630	.68276	.00390	.25241
		$y_{(1000)} = 3.71 + 0.2800x_1$		$s_e = 0.40$	
General Utility	x_1	.65702	.43168	.43166	.65702
	x_2	.72216	.52152	.08984	.60855
	x_3	.72275	.52237	.00085	-.00273
	x_4	.72924	.53179	.00943	-.12826
	x_5	.73546	.54090	.00911	.09915
		$y_{(1000)} = 8.99 + 0.2586x_1$		$s_e = 1.65$	
Basic & General Transport	x_1	.81553	.66509	.66509	.81553
	x_2	.82158	.67500	.00991	.61456
	x_3	.83650	.69973	.02472	-.09715
	x_4	.83655	.69981	.00009	-.23342
	x_5	.86113	.74155	.04174	.33867
		$y_{(1000)} = 21.36 + 0.225x_1$		$s_e = 3.25$	

TABLE 12

MULTIPLE REGRESSIONS
ITINERANT OPERATIONS

	Variable	Multiple R	R^2	ΔR^2	Simple r
All Airports	x_1	.88952	.79143	.79143	.88962
	x_2	.89140	.79459	.00317	.66640
	x_3	.89157	.79490	.00030	-.18189
	x_4	.89216	.79595	.00105	-.07543
	x_5	.89525	.80147	.00552	.13767
	$y_{(1000)} = 1.82 + 0.2532x_1$			$s_e = 0.47$	
Basic Utility	x_1	.83581	.69859	.69859	.83581
	x_2	.84165	.70838	.00980	.58102
	x_3	.84424	.71272	.00435	-.04877
	x_4	.85271	.72711	.01437	-.18744
	x_5	.85301	.72762	.00051	.10174
	$y_{(1000)} = 2.16 + 0.1735x_1$			$s_e = 0.32$	
General Utility	x_1	.86126	.74177	.74177	.86126
	x_2	.86144	.74208	.00031	.45026
	x_3	.86158	.74232	.00025	.08093
	x_4	.86583	.74967	.00734	-.11784
	x_5	.86936	.75579	.00612	.04947
	$y_{(1000)} = 1.87 + 0.2525x_1$			$s_e = 0.82$	
Basic & General Transport	x_1	.90684	.82236	.82236	.90684
	x_2	.90902	.82632	.00390	.76260
	x_3	.91250	.83265	.00633	.02224
	x_4	.91340	.83430	.00165	-.17502
	x_5	.93654	.87711	.04282	.21458
	$y_{(1000)} = 13.83 + 0.2797x_1$			$s_e = 2.40$	

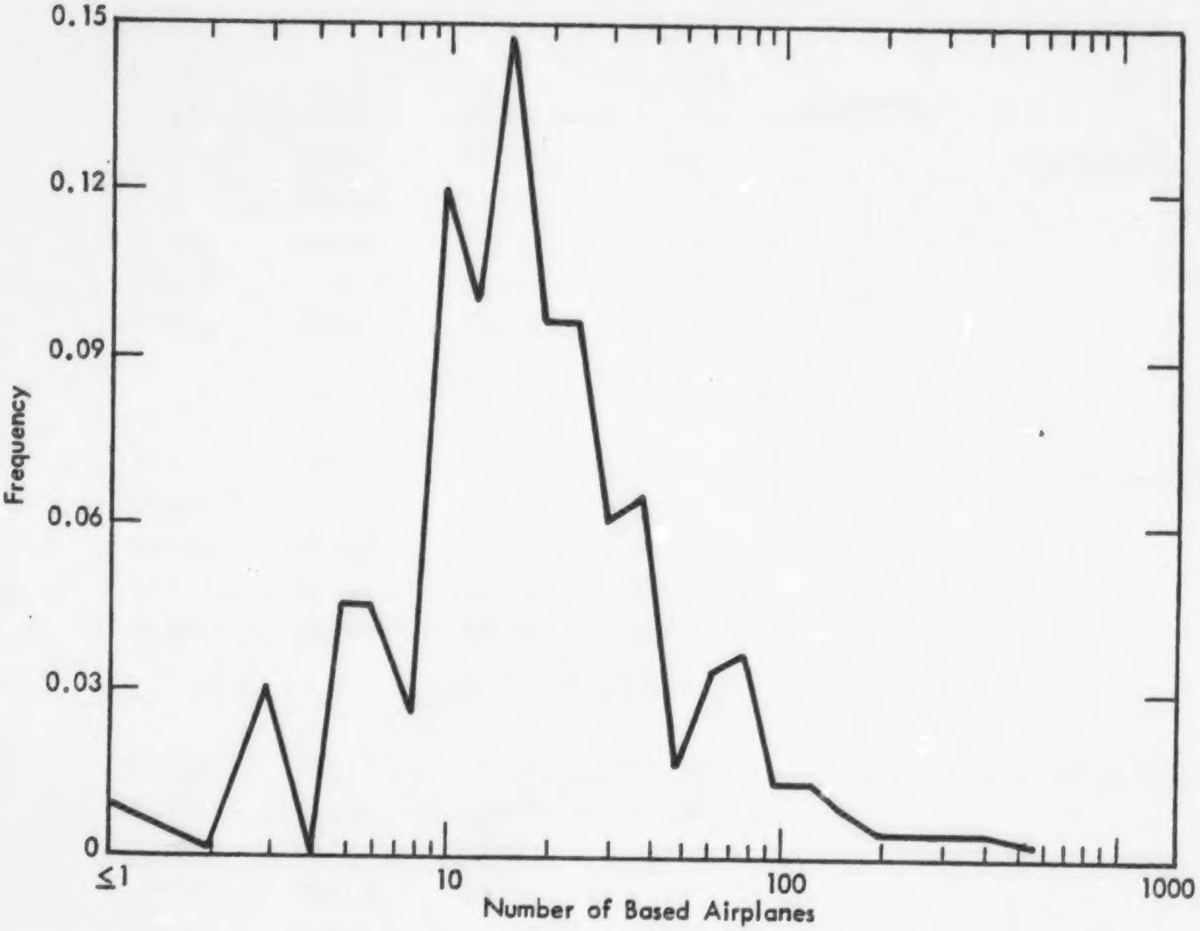

FIGURE 19. FREQUENCY POLYGON OF BASIC UTILITY AIRPORTS AS A FUNCTION OF NUMBER OF BASED AIRPLANES

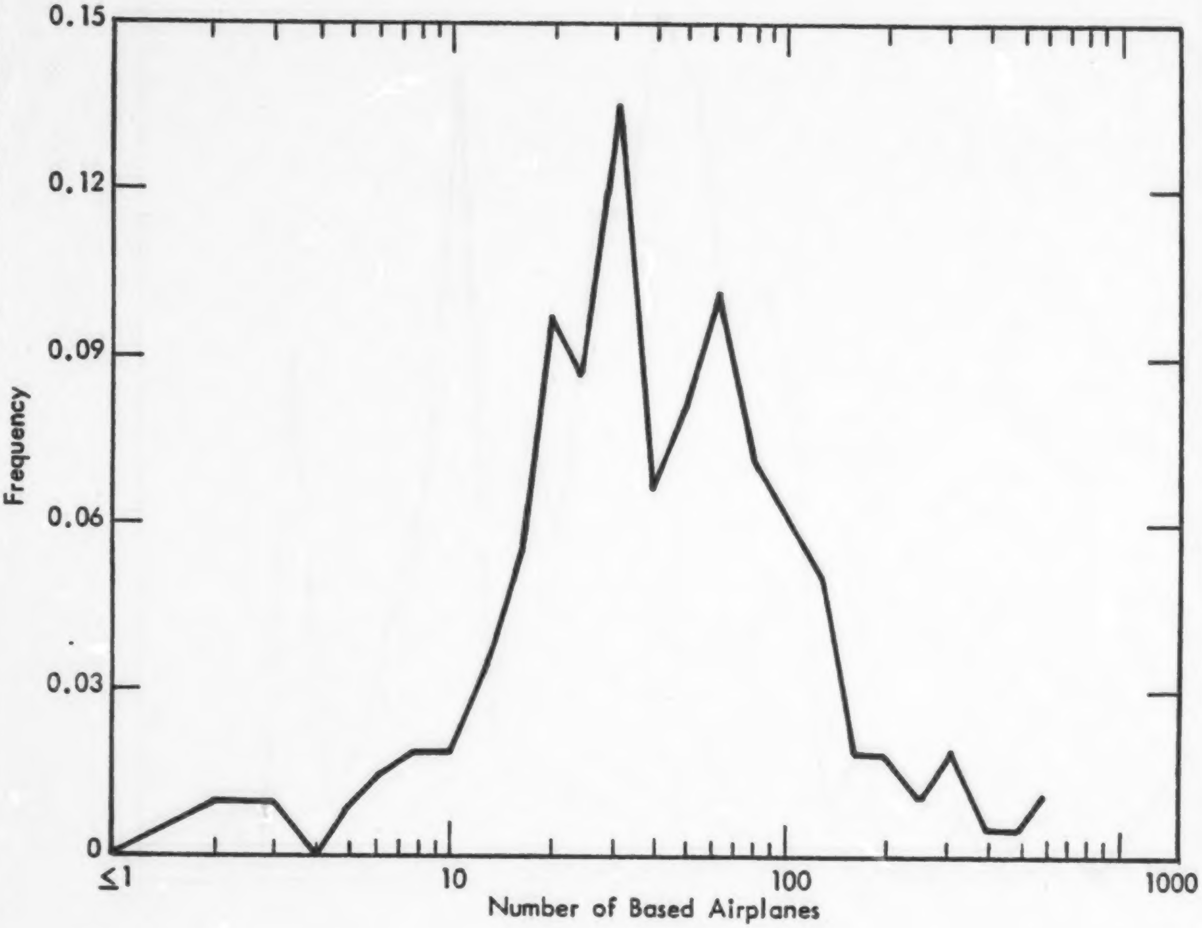

FIGURE 20. FREQUENCY POLYGON OF GENERAL UTILITY AIRPORTS AS A FUNCTION OF NUMBER OF BASED AIRPLANES

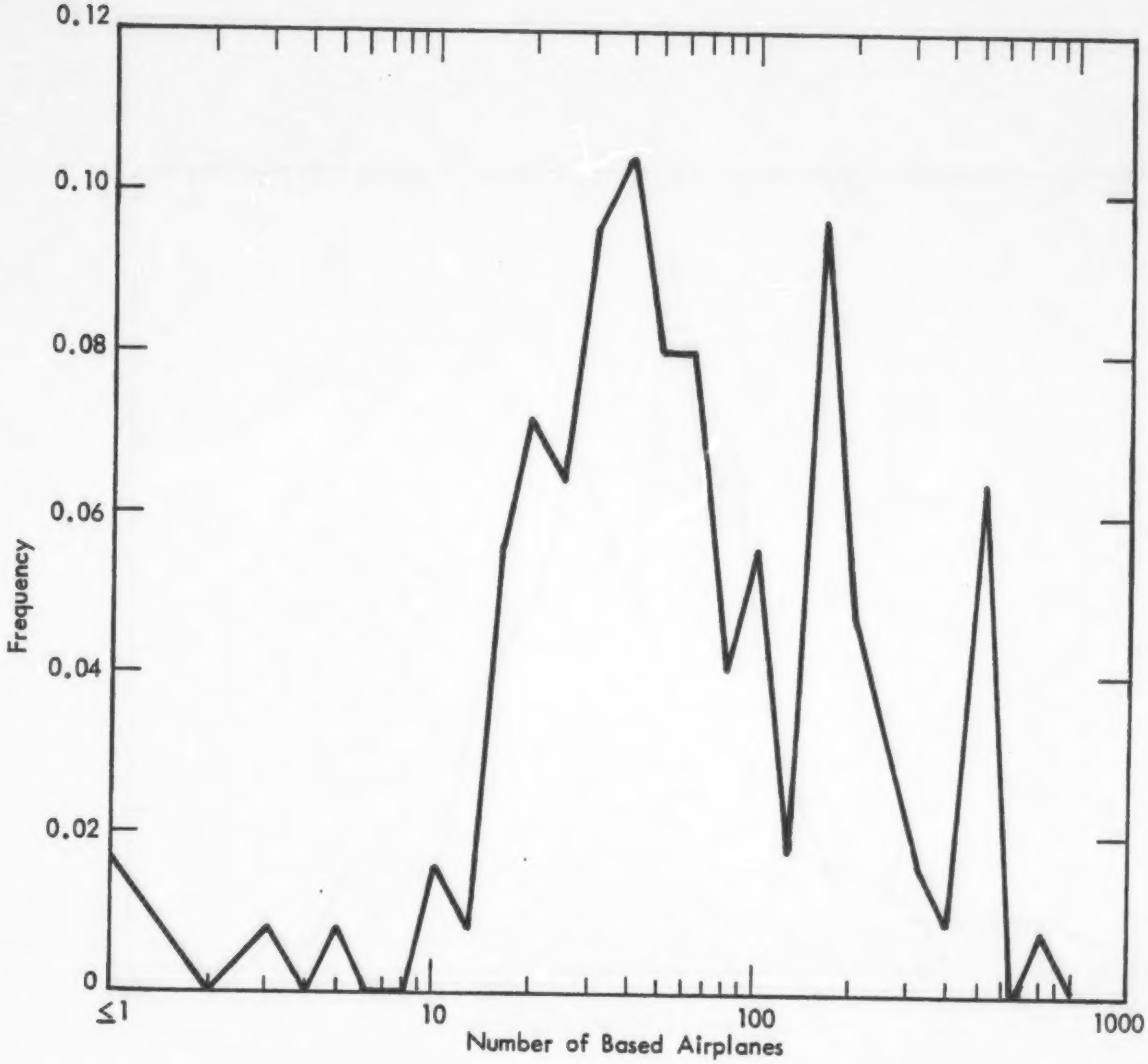

FIGURE 21. FREQUENCY POLYGON OF BASIC & GENERAL TRANSPORT AIRPORTS AS A FUNCTION OF NUMBER OF BASED AIRPLANES

general utility, and transport airports in this sample. Community noise is proportional to the logarithm of number of operations, and hence number of based airplanes. In constructing the frequency polygons the number of airports having specified numbers of based airplanes have been aggregated into class intervals of based airplanes, where each class is 1.26 times the size of the previous class. This corresponds to one decibel increments if the constant of proportionality relating sound level to logarithm of operations is 10.

5.4 Population Distribution Around General Aviation Airports

One of the purposes of this study is to develop an estimate of the number of people exposed to community noise from GA airports at different day-night average sound levels. To calculate this accurately would require a detailed map of population distribution around every airport, involving resources that are several orders of magnitude greater than available for this study. For this study it was decided to separate airports into three population classes, determined by the geographic relationship of the airports to the communities they serve. The three categories were designated rural, suburban-rural, and urban.

Assignment of the 771 sample airports to one of the three population classes was done on an individual basis. Airports located greater than two miles from the boundary of the built-up area of a community were considered rural. Airports located between the built-up area and two miles were considered suburban-rural. Airports adjacent to or within built-up areas were considered urban. Each airport was assigned to one of the three classes on the basis of its location on the appropriate World Aeronautical Chart, which also depicts the built-up area for communities.

Population densities assumed in the analyses of Section 6 of this report are 50 people per square statute mile for rural areas, 200 per square mile in suburban-rural, and 5000 per square mile in urban areas. Alternate assumptions can be used for other analyses since the airport assignments to population classes have been retained. An indication of the distribution of airports by airport role and population class is shown in Figure 22.

5.5 Area Models For Community Noise at General Aviation Airports

The day-night average sound level (DNL) at any point around an airport is given by the following equation:

$$L_{dn} = \overline{L_{AE}} + 10 \log_{10} N - 49.4 \qquad (6)$$

where $\overline{L_{AE}}$ is the mean-square sound exposure level (SEL) at the receiver location, produced by N effective operations, where N is the annual average number of operations between 7:00 a.m. and 10:00 p.m., plus 10 times the number of operations between 10:00 p.m. and 7:00 a.m. The constant 49.4 is 10 times the logarithm of the ratio of number of seconds in 24 hours to the one second reference period for sound exposure level. Mean-square SEL is determined from the SEL for individual airplane types weighted by the number of events of that type.

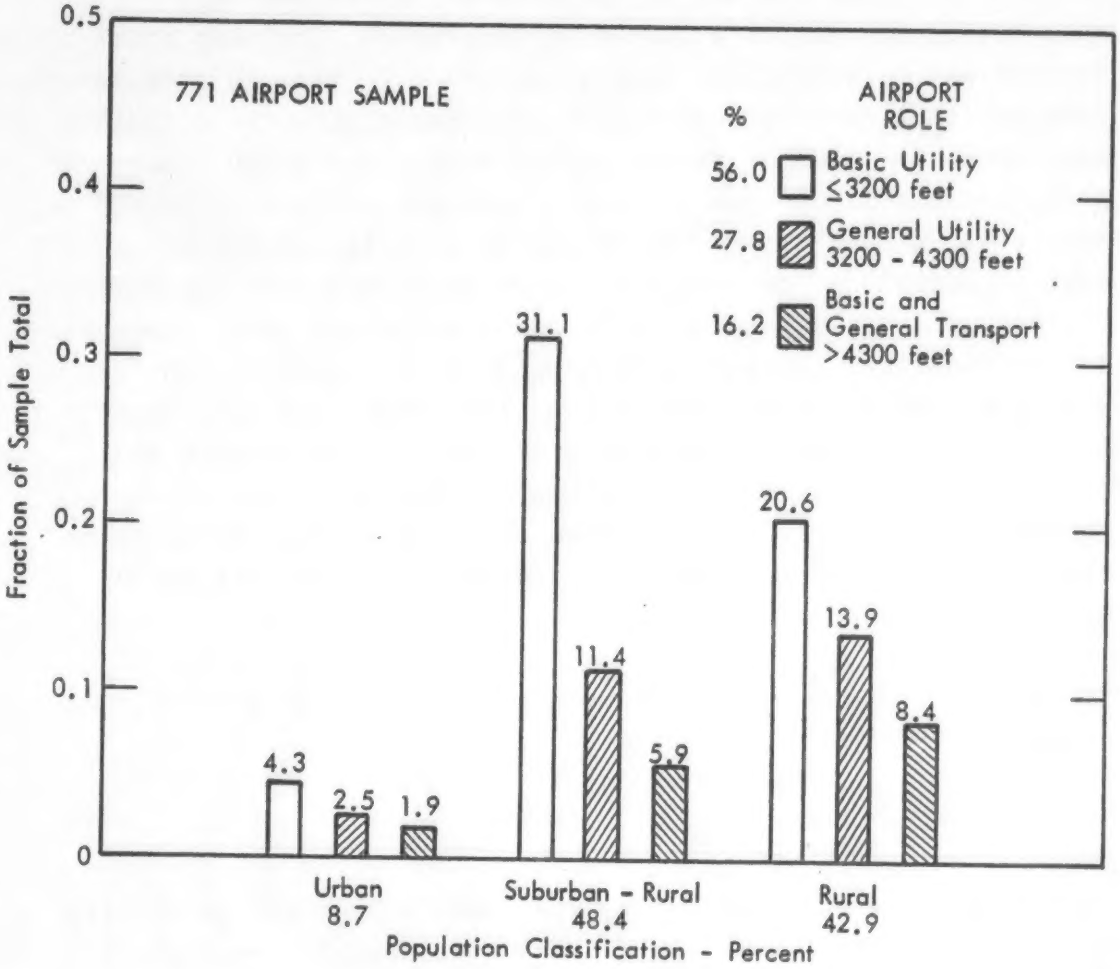

FIGURE 22. FRACTION OF AIRPORTS SORTED BY AIRPORT ROLE AND POPULATION CLASS

Contours of equal DNL may be computed for an airport by calculating the SEL at a number of locations. The most expeditious way to accomplish this computation is through computer programs that combine the flight performance data for different airplanes, in terms of flight paths, speed, and power management, and the SEL versus distance functions for the different airplanes to compute the DNL values at a series of points. Such computations for this study were performed with the NOISEMAP[11] program, using the performance and sound level characteristics described earlier in Section 3 of this report. In previous studies it has been shown that where area of a contour alone is of interest, simulations of all operations from an airport by assuming them all to operate from a single runway provides essentially the same area as is calculated if multiple runways were actually used. All computations for this study use the single runway method.

The area for DNL contours around airports is related to DNL by a general expression of the form:

$$L_{dn} = a - b \log_{10} A \tag{7}$$

where a and b are determined by the total number and particular mix of operations. Examples of this relationship are shown in Figure 23 for 2 and 20 operations per day of jets representing the 1975 composite business jet fleet and in Figure 24 for 200 and 2000 operations per day of composite small prop airplanes.

Several features can be noted in these figures. Over the DNL range of interest, regressions of DNL versus the logarithm of area are represented by straight lines, with almost perfect

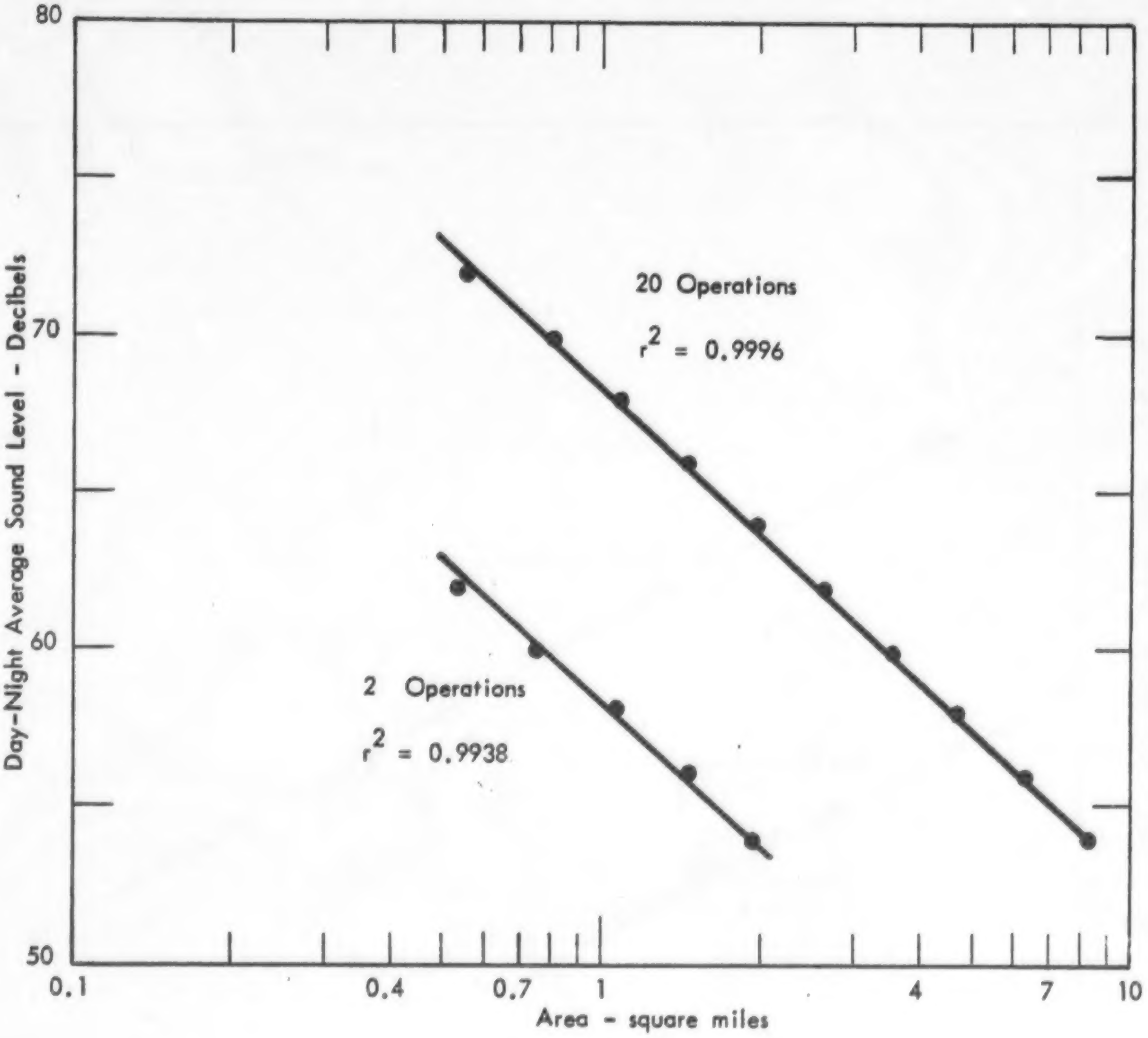

FIGURE 23. DAY-NIGHT AVERAGE SOUND LEVEL CONTOUR AREAS FOR 1975 COMPOSITE BUSINESS JETS, STANDARD TAKEOFF PROCEDURES

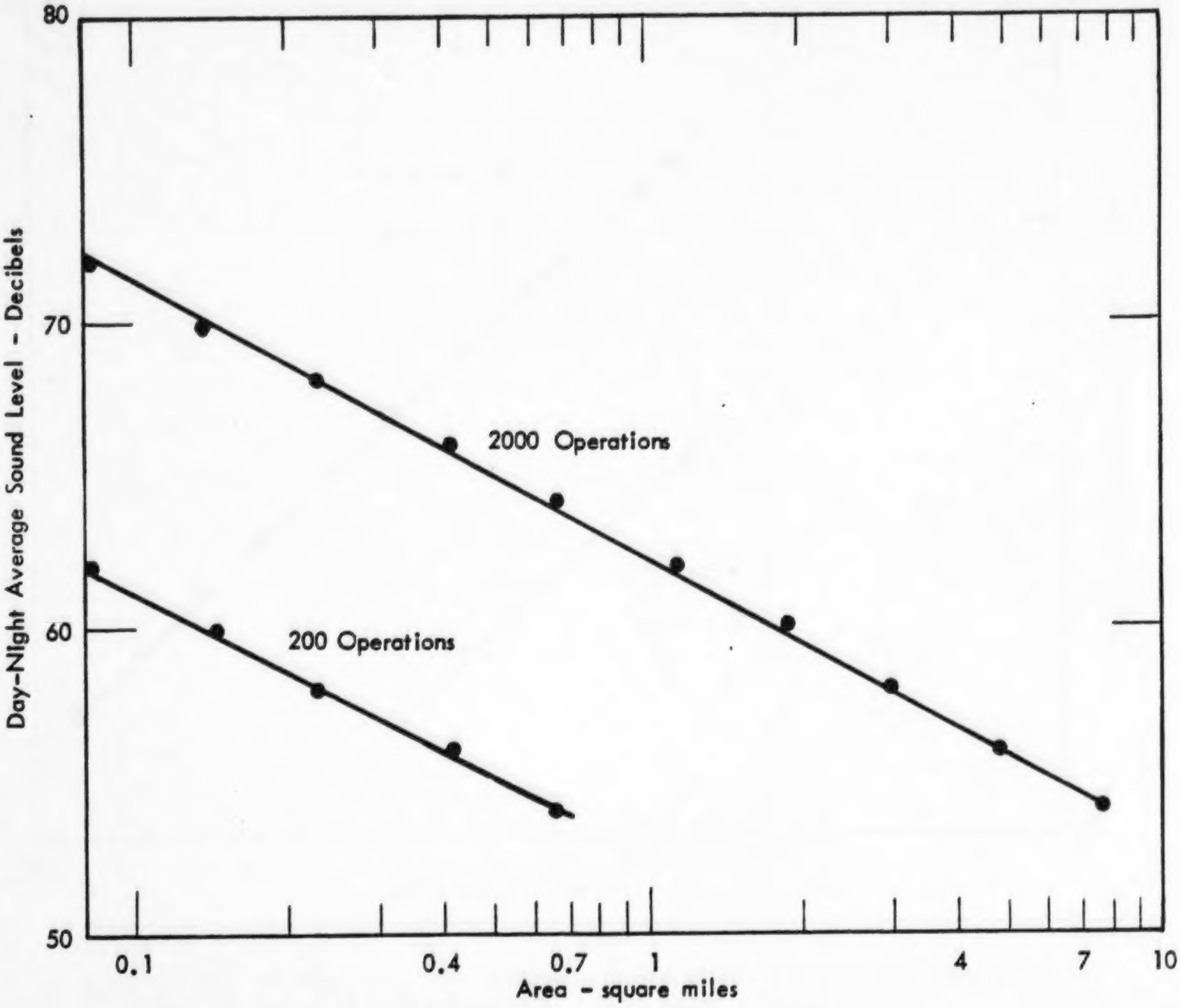

FIGURE 24. DAY-NIGHT AVERAGE SOUND LEVEL CONTOUR AREAS FOR COMPOSITE PROPELLER DRIVEN SMALL AIRPLANES

correlation. For a fixed fleet composition (Figures 23 and 24), regression lines with different numbers of operations are parallel, being displaced only in absolute value. The slopes of the lines are different for different fleet compositions, as are the intercepts.

Changes in fleet composition or operating procedures, holding total number of operations constant, will change both the slope and intercept in the regression equations. For example, in Figure 25, the different regressions lines for the combination of business jets and small props, with 400 total operations per day, are shown alternately with 2 percent of the total being jets and one-half percent jets. The difference in DNL contour area for 20 jet operations per day using the standard jet departure and the NBAA noise abatement departures, described in Section 3, are shown in Figure 26. Changes in DNL versus area for the composite jet fleet at the different 5 year intervals from 1975 to 2000 are shown in Figure 27 for 400 total operations per day, 2 percent jets, 98 percent small props.

Analytical expressions can be written to represent any of the DNL versus area functions in a form useful for computation. Equation (6) can be rewritten in the form:

$$L_{dn} = \alpha + 10 \log_{10} N - \beta \log_{10} A \qquad (8)$$

where α and β are determined empirically for different fleet compositions by regression analysis of DNL versus contour areas calculated from NOISEMAP. A more useful form is to transform Equation (7) to express area in terms of the other parameters:

$$A = \left(10^{\frac{\alpha}{\beta}}\right)\left(N^{\frac{10}{\beta}}\right)\left(10^{-\frac{L_{dn}}{\beta}}\right) \qquad (9)$$

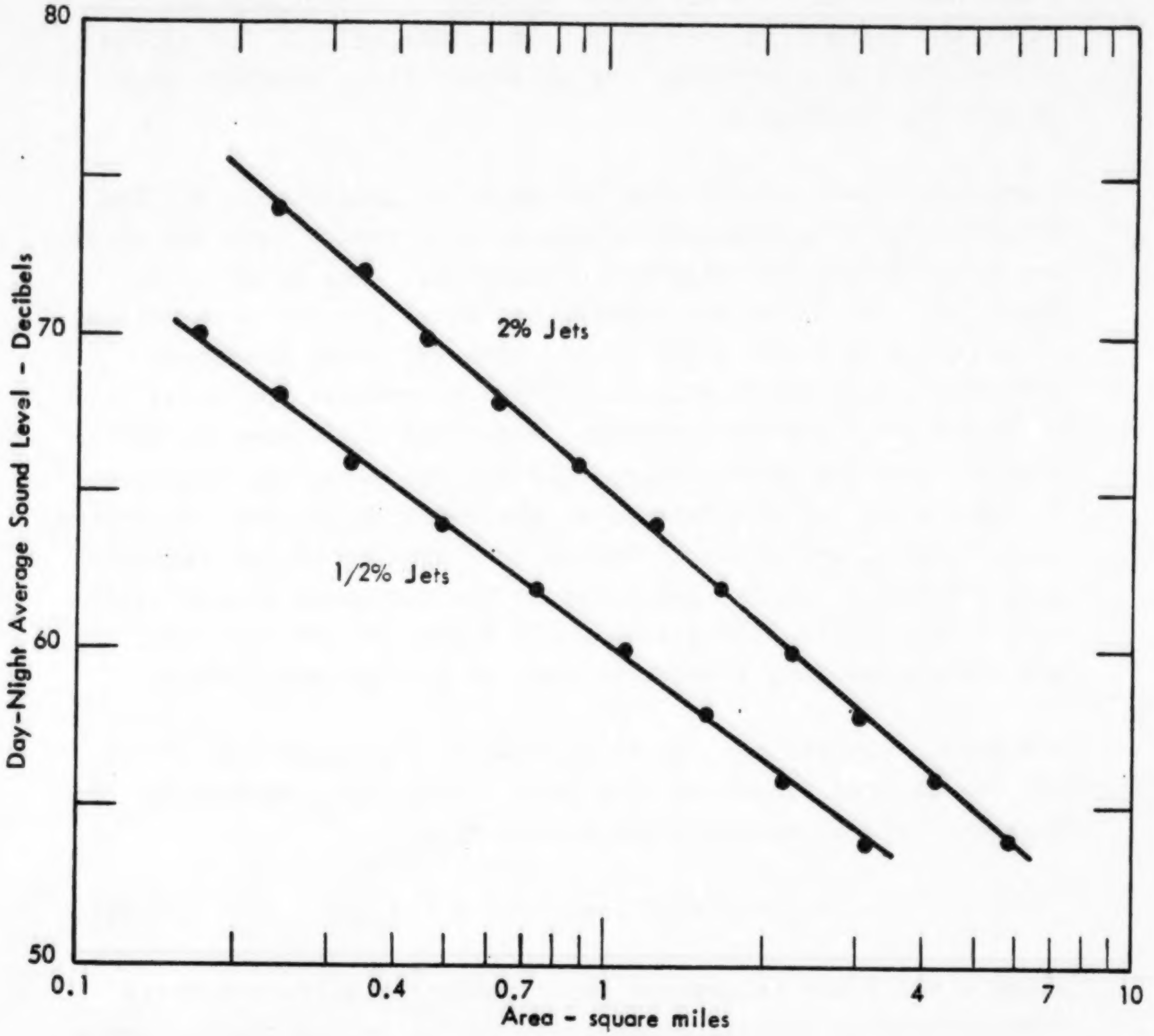

FIGURE 25. DAY-NIGHT AVERAGE SOUND LEVEL CONTOUR AREAS - MIXED 1975 FLEET - 400 OPERATIONS PER DAY - 1/2% AND 2% JETS

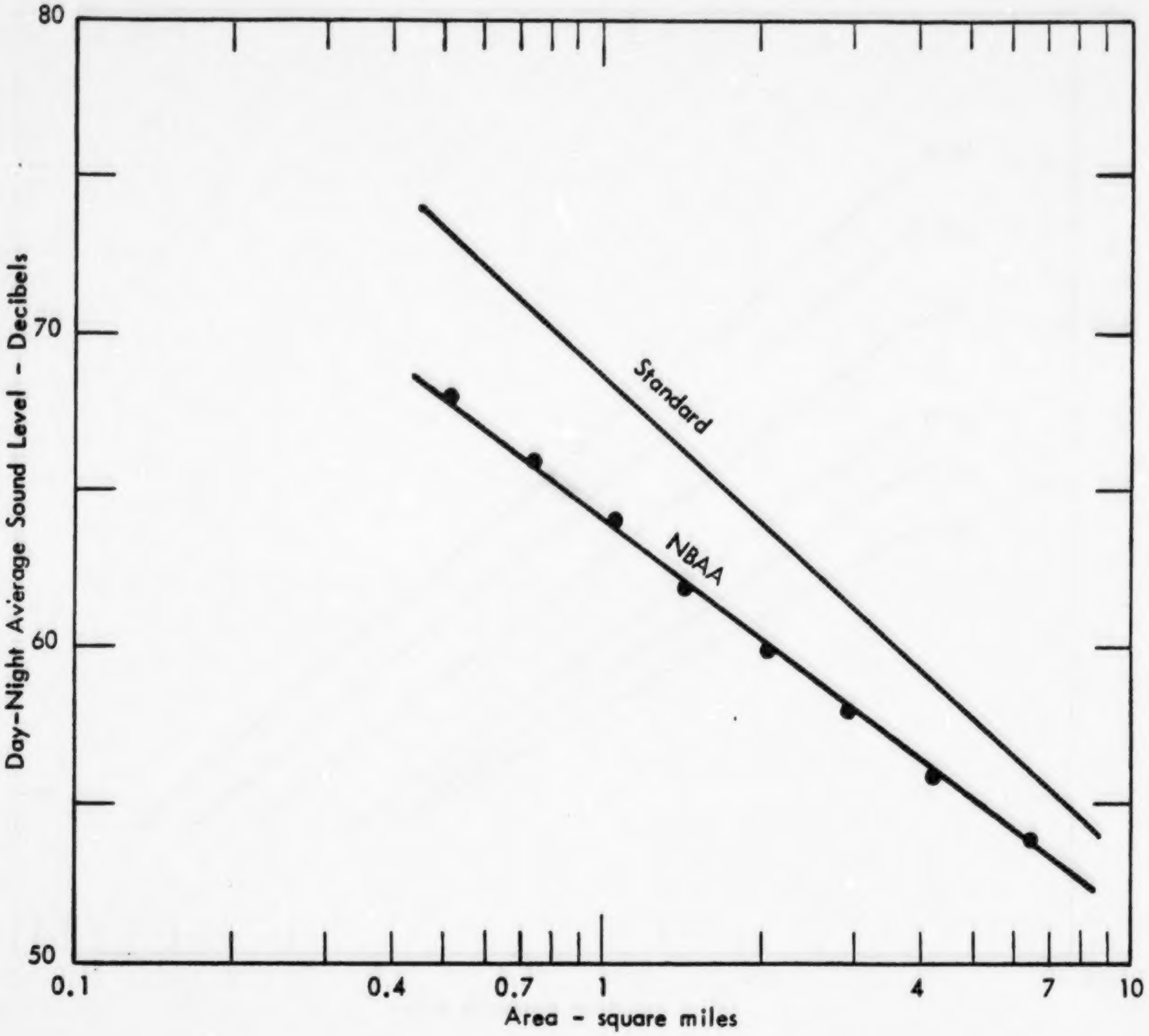

FIGURE 26. DAY-NIGHT AVERAGE SOUND LEVEL CONTOUR AREAS 1975 COMPOSITE BUSINESS JET - 20 OPERATIONS PER DAY - STANDARD AND NBAA TAKEOFF PROCEDURES

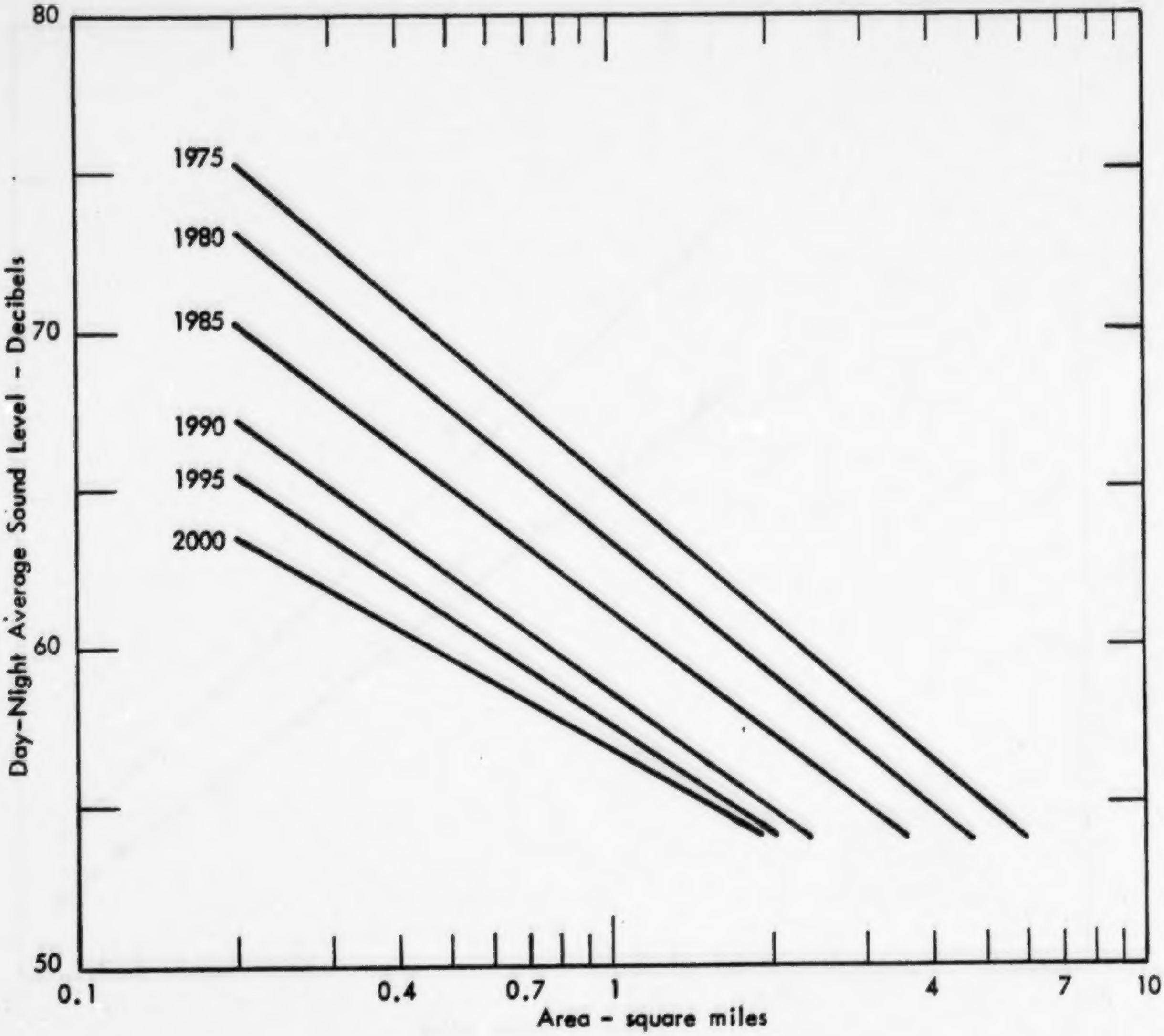

FIGURE 27. DAY-NIGHT AVERAGE SOUND LEVEL CONTOUR AREAS FOR YEARS 1975 TO 2000; 400 OPERATIONS PER DAY, 2% JETS

It is often useful to compare the ratio of the area for one combination of parameters to the area with a different set of parameters. The general expression, with all parameters different, is:

$$\frac{A_2}{A_1} = \left[10^{\frac{(\alpha_2\beta_1-\alpha_1\beta_2)}{\beta_1\beta_2}}\right]\left[\frac{N_2^{\frac{10}{\beta_2}}}{N_1^{\frac{10}{\beta_1}}}\right]\left[10^{-\frac{L_{dn_2}}{\beta_2}+\frac{L_{dn_1}}{\beta_1}}\right] \tag{10}$$

Several special cases yield particularly simple area ratios. For example, with the same fleet composition and the same DNL, the ratio of areas with different values of number of operations is:

$$\frac{A_2}{A_1} = \left(\frac{N_2}{N_1}\right)^{\frac{10}{\beta}} \tag{11}$$

Another useful relationship holds for the ratio of areas of different DNL values with all other parameters constant. That is, if $\Delta = L_{dn_2} - L_{dn_1}$

then

$$\frac{A_2}{A_1} = 10^{-\frac{\Delta}{\beta}} \tag{12}$$

Values for the parameters α and β applicable to various conditions used in this study are listed in Table 13. Also listed, for future reference, is the ratio of number of airplanes in the GA fleet at future years to the number in 1975. The values listed in the column labeled "Jet Δ SEL" are the average offset in the SEL versus distance functions for the composite jet fleet for various future years. These values come from Figure 17.

TABLE 13

DAY/NIGHT AVERAGE SOUND LEVEL AREA MODEL PARAMETERS IN TERMS OF AVERAGE DAILY OPERATIONS, N, AREA IN SQUARE MILES

$$A = N^{\frac{10}{\beta}} \, 10^{\frac{\alpha - \mathrm{Ldn}}{\beta}}$$

2% Jets	α	β	$\frac{N_{19xx}}{N_{1975}}$	Jet Δ SEL
1975	38.9560	14.3223	1.000	0
1980	37.0690	13.6480	1.255	-2.2
1985	35.1048	13.0574	1.621	-5.1
1990	31.8919	10.4055	1.912	-10.7
1995	31.1125	9.7939	2.186	-13.7
2000	30.7075	9.3556	2.415	-15.7
Props	29.0491	9.1167		

Airport Area Models

Basic Utility	$A = 0.072\ N_B^{0.2818}$
General Utility	$A = 0.126\ N_B^{0.2818}$
Transport	$A = 0.359\ N_B^{0.2059}$

N_B is number of based airplanes

The models for computing DNL described above yield the total contour area. For many airports all or much of some DNL contour areas will fall within the boundaries of the airports. In order to estimate the DNL contour area outside airports an estimate of airport size is required. It seems logical to assume that airport area will vary with both the airport role, hence runway length, and with the number of airplanes based at the airport (due to additional parking space, cross-wind runways, taxiways). The following rationale for airport sizes is used in this study, in terms of the number of based airplanes, N_B.

Basic utility airports, runway less than 3200 feet long

$N_B = 1$ 1000 feet x 2000 feet
$N_B = 500$ 3000 feet x 3000 feet

General utility airports, runway length between 3200 and 4300 feet

$N_B = 1$ 1000 feet x 3500 feet
$N_B = 500$ 4500 feet x 4500 feet

Transport airports, runways more than 4300 feet long

$N_B = 1$ 2000 feet x 5000 feet
$N_B = 500$ 4000 feet x 9000 feet

Analytic expressions expressing these assumptions for area in square statute miles are listed in Table 13.

5.6 Application of Models to Airports

The previous sections of this report have described the basic tools used to develop the area of DNL contours around airports with different role classifications and numbers of based airplanes. These tools are applied in this section to provide design charts that yield information about contour areas, shapes and sizes. First, however, two further assumptions need to be made before combining the results. One relates to the ratio of daytime to nighttime operations and the other to the ratio of jet operations to small prop operations for airports capable of accepting jets.

Consider first the daytime-nighttime distribution of operations. Little data are available to establish such numbers. At the few airports where such data were available to the authors, the nighttime operations range from essentially zero to a high of 2 percent, with one-half percent being typical. These numbers are associated with airports having control towers, instrument approach facilities, lighted and paved runways, hardly typical of the national average GA airport. The effect of one-half percent nighttime operations on DNL is to increase the average sound level, with no nighttime operations, by 0.2 decibels, for the same total number of operations. At 2 percent the increase is 0.7 decibel. These effects are imperceptable within the accuracy of the assumptions of this study. In the following analyses no effect of nighttime operations is considered.

Operations of transport airports are assumed to include business jets. The fraction of total operations performed by jets at these airports needs to be specified. Information in the FAA activity studies[10/] provides various forms of data from which some estimates can be made. Based on the number of hours flown per year and average trip durations for itinerant operations, the number of operations per hour in local flying, and the relative percentages of itinerant to local flights by jets and small props, business jets performed 0.27 percent of total GA operations, using 1978 total operations data.

If one assumes business jets operate only from public use airports with paved and lighted runways, and that one-half of the operations are at airports that are without control towers and are not air carrier airports, then jets produce 0.26 percent of total operations at these airports. If one assumes that 20 percent of all business jet operations take place at airports with control towers but no air carrier service, business jets produce 0.39 percent of these total operations.

While these broad estimates would indicate that, on average, jets could produce about one-quarter to one-half of the operations at those GA airports in the transport role, data from some airports with high business jet activity indicate that they constitute as much as 2 percent or more of total operations. If 2 percent of total operations were attributed to business jets at transport role airports as a national average, the resulting computations extrapolated to a national estimate should be quite conservative, in that the total noise exposure would likely be overstated. This assumption is used for the analyses reported here.

With these assumptions and the results of the material described earlier in this report, the DNL areas for the different airport models have been calculated, using number of based airplanes to estimate the total number of operations. The results of the computations for the 1975 baseline fleets are shown in Figure 28 for basic utility airports, Figure 29 for general utility airports, and Figure 30 for transport airports. No jet operations are incorporated in the basic-utility and general utility calculations, although inclusion of Citations at up to several percent of total operations would not change the result. The results shown in Figure 30 for transport airports assume 2 percent of total operations are performed by jets that have composite sound levels for the 1975 fleet.

Historical data show that the number of hours flown on an annual basis, and the average trip lenth distribution by airplane type are very stable. If this remains so in the future, one may use the figures for basic and general utility airports to estimate the future change in DNL as the number of based airplane changes at an airport.

This is not so for the transport airport data, Figure 30, since the DNL area for a fixed number of based airplanes will decrease with time as the composite sound levels are reduced by addition of turbofan airplanes and phasing out of turbojets. This change with time is illustrated in Figure 31 where the total area of the 55 DNL contour and the area outside the assumed airport size are shown for 150, 300, and 700 operations per day at the various 5 year intervals from 1975 to 2000. Estimates of DNL contour areas for future operations must combine the growth due to increased numbers of airplanes with the decrease in sound level of future fleet compositions.

While the area of a DNL contour is a primary measure of the extensiveness of community noise from aircraft operations, it

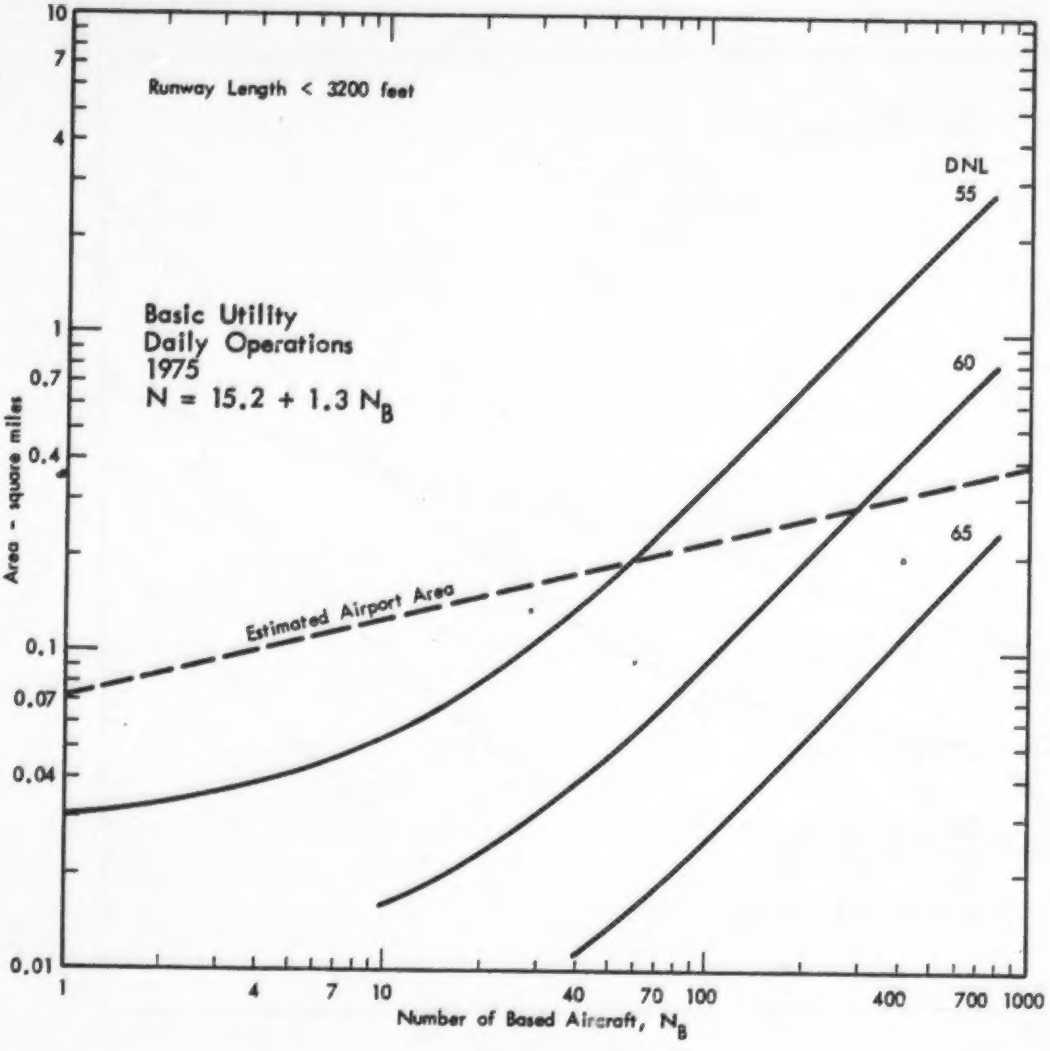

FIGURE 28. AREA ENCLOSED WITHIN VARIOUS CONTOURS OF DAY-NIGHT AVERAGE SOUND LEVEL AS A FUNCTION OF THE NUMBER OF AIRPLANES BASED AT A BASIC UTILITY AIRPORT

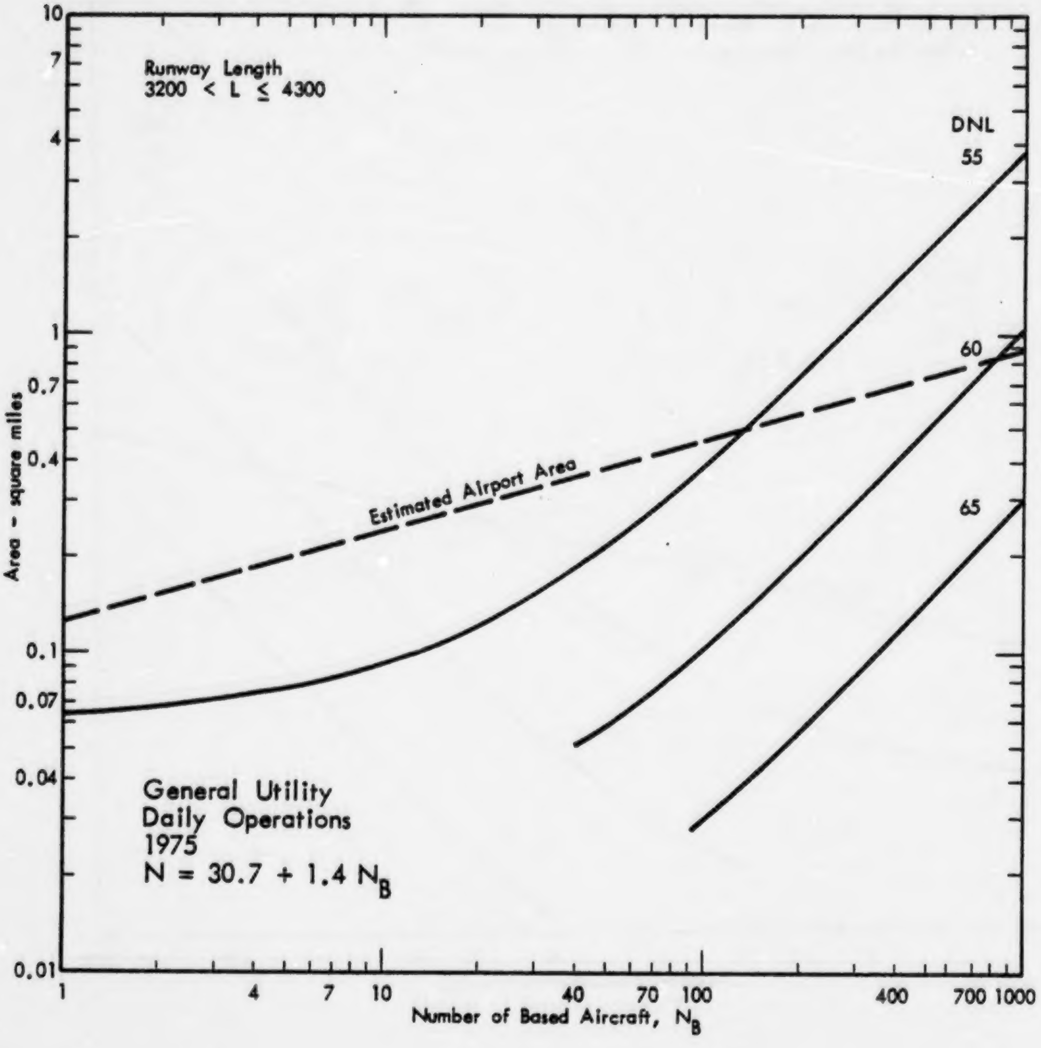

FIGURE 29. AREA ENCLOSED WITHIN VARIOUS CONTOURS OF DAY-NIGHT AVERAGE SOUND LEVEL AS A FUNCTION OF THE NUMBER OF AIRPLANES BASED AT A GENERAL UTILITY AIRPORT

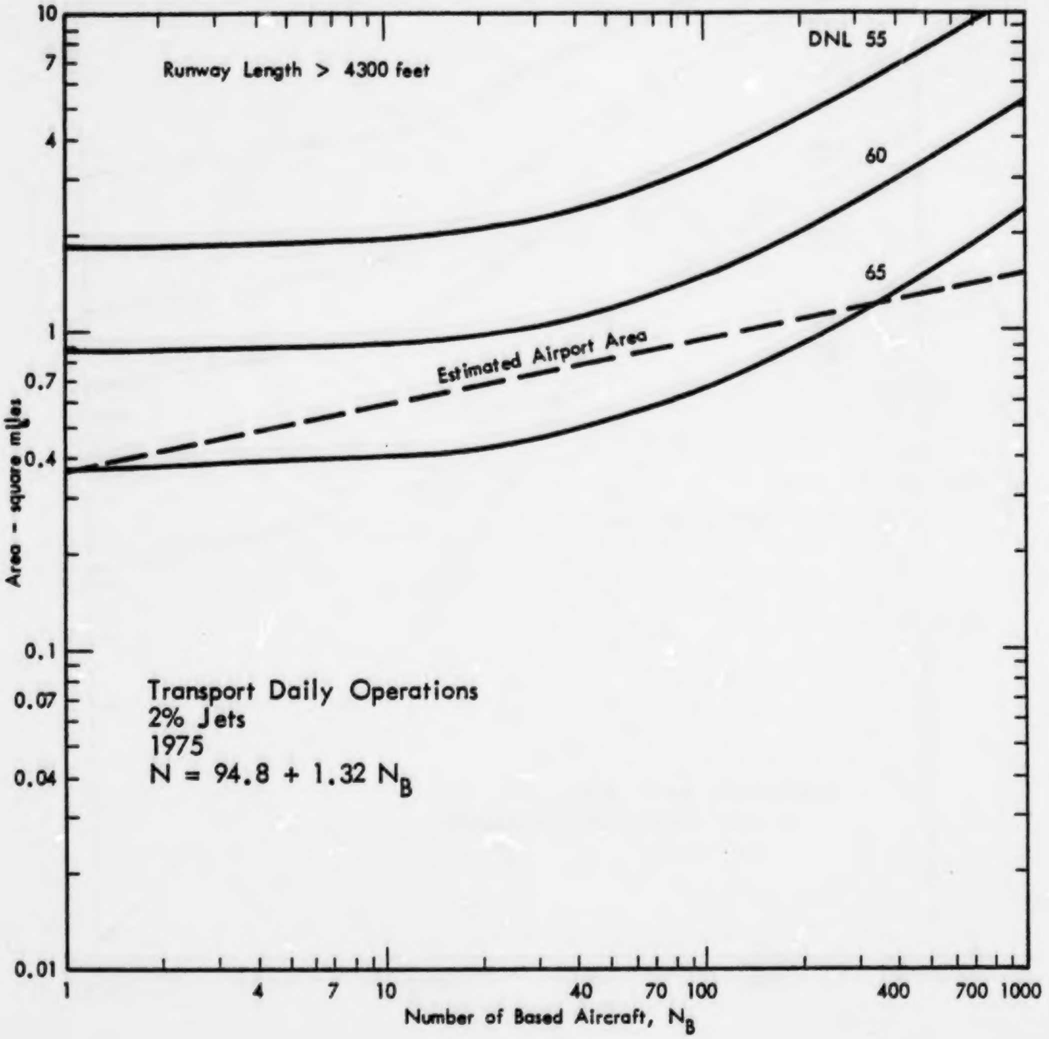

FIGURE 30. AREA ENCLOSED WITHIN VARIOUS CONTOURS OF DAY-NIGHT AVERAGE SOUND LEVEL AS A FUNCTION OF THE NUMBER OF AIRPLANES BASED AT A TRANSPORT AIRPORT

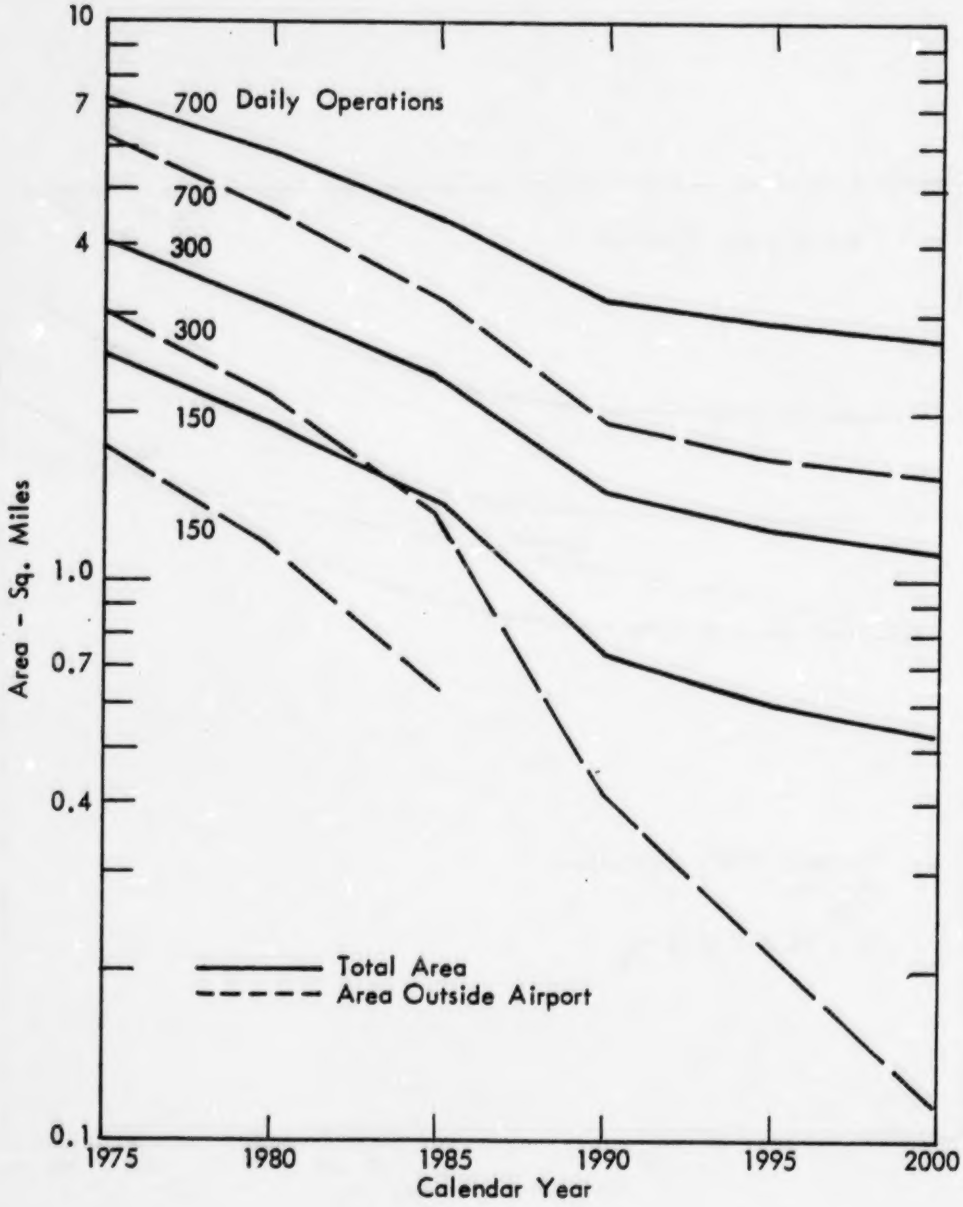

FIGURE 31. TRANSPORT AIRPORTS - 2% JETS: CHANGE IN 55 DNL CONTOUR AREA WITH TIME FOR FIXED NUMBER OF OPERATIONS

tells nothing about the shape of the contours. It is impossible to provide detailed contour shape information without examining each airport in detail. Nevertheless, some general guidelines can be given.

The predominant part of a noise contour for GA airplanes is caused by takeoff operations. An estimate of the takeoff contour shape can be made by first determining the distance to the point of closure of the contour from the start of takeoff roll. This point can be calculated if one knows SEL as a function of the distance along the flight track from start of takeoff roll. This function is determined by summing the SEL contributions from different airplane types at various distances along the flight track. Data for small props alone, and for mixed fleets composed of small props and business jets (2% jets) for the composite fleets at different 5 year time intervals are shown in Figure 32.

The distance to closure of a DNL contour may be calculated from Figure 32 by using the basic relationship between DNL, mean square average SEL, and number of operations:

$$L_{dn} = \overline{L_{AE}} + 10 \log_{10} N - 49.4 \qquad (13)$$

For example, consider an airport having 400 total operations per day. Half of these will be takeoffs and half landings. If 60 percent of takeoffs are from one runway, find the distance of closure for the 60 DNL contour. In this case, $\overline{L_{AE}}$ is given by:

$$\overline{L_{AE}} = 60 + 49.4 - 10 \log_{10} \left[0.6 \times 0.5 \times 400\right]$$

$$\therefore \overline{L_{AE}} = 88.6$$

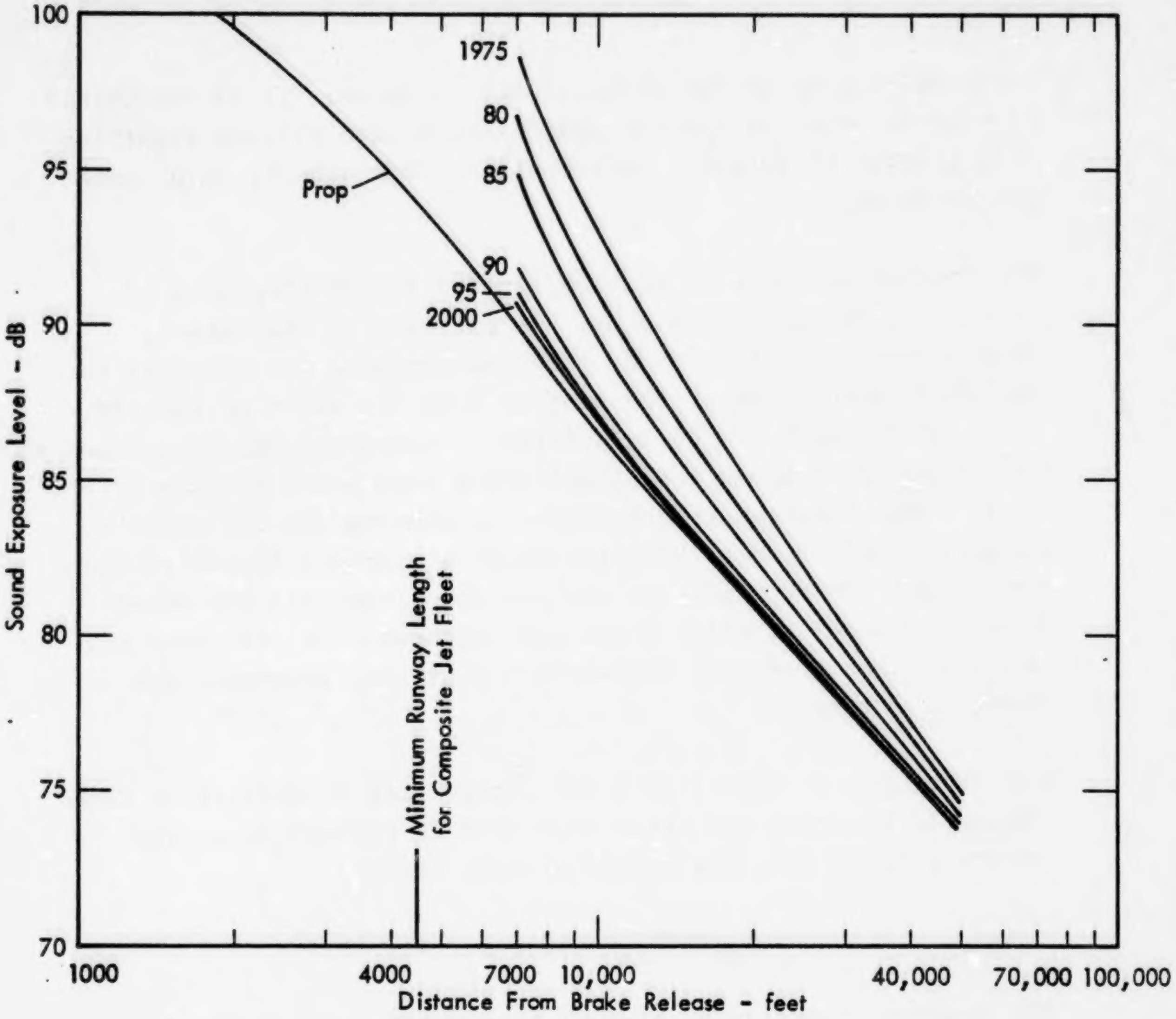

FIGURE 32. DISTANCE TO SOUND EXPOSURE LEVEL CONTOUR CLOSURE POINT - TAKEOFF MIXED FLEET - 2% JET FOR YEARS 1975 TO 2000

From Figure 32, with props alone the contour closes at 8000 feet from start of takeoff. For a mixture of 2 percent jets with props, the contour closes at 15,000 feet for the 1975 baseline fleet.

The shape of the takeoff contour along the distance from start of takeoff to contour closure can also be generalized to obtain the area enclosed at various distances along the takeoff flight track. Area density and cumulative area as a function of the distance along the flight track are shown in Figure 33. As an example, the cumulative area function shows that half of the contour area occurs by 0.46 of the distance from start of roll to contour closure for the 1975 small props and the 1990 jet fleet; and at 0.52 of this distance for the 1975 jet fleet.

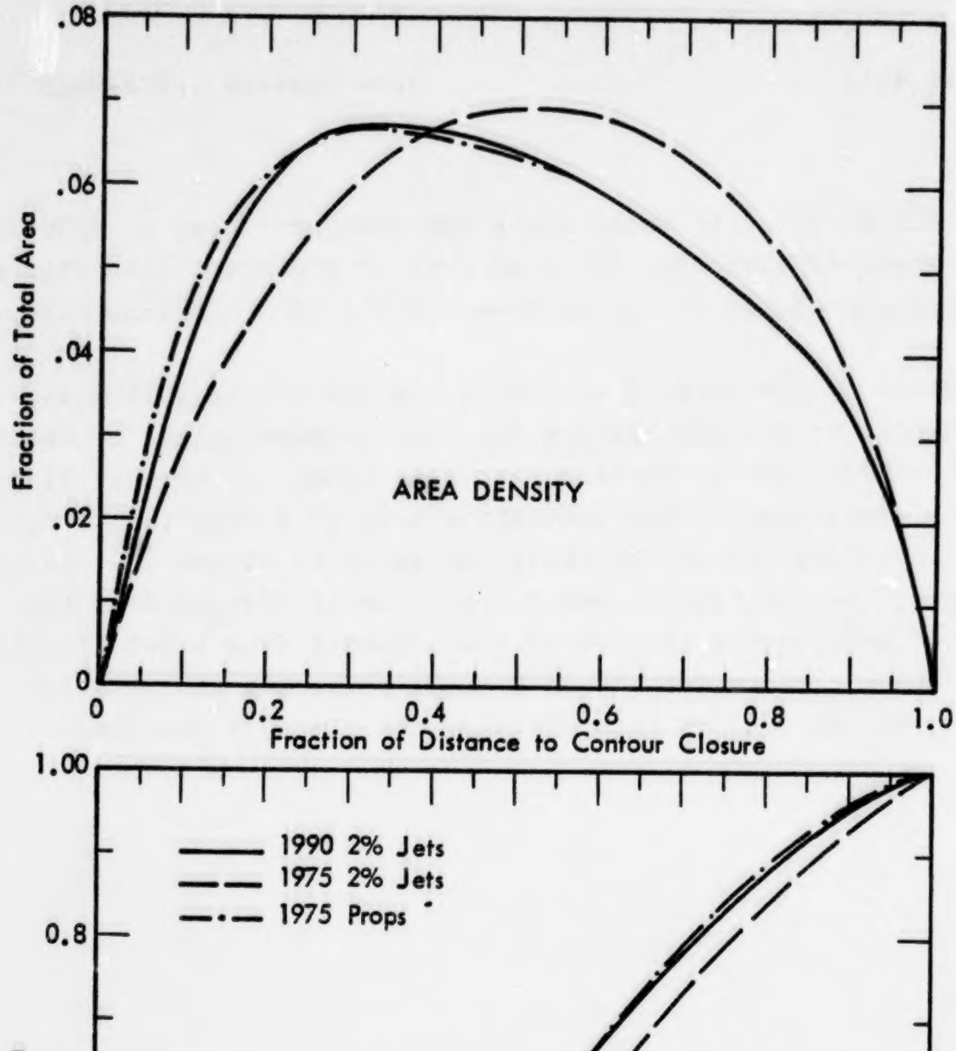

FIGURE 33. GENERALIZED SOUND EXPOSURE LEVEL AREA FUNCTIONS - TAKEOFF

6.0 ESTIMATION OF AREAS AND POPULATION EXPOSED TO GENERAL AVIATION AIRPORT NOISE

6.1 General Assumptions

In the earlier sections of this report it was stated that 93 percent of all general aviation operations take place at approximately 6000 public use airports, and thus 7 percent take place at the remaining 6000 private use airports. It was also shown that it requires on the order of 50 based airplanes at airports with runways up to 3200 feet long to generate the number of operations necessary for a 55 DNL contour to extend beyond the airport boundaries. It is assumed here that at private use airports there are insufficient operations to generate a 55 DNL contour beyond the airport boundary.

Over half of the public use airports in the country are included in the National Airport System Plan (NASP), or approximately one-quarter of all airports. On the other hand, three-quarters of all registered aircraft in the country are based at airports included in the NASP. Essentially all communities within the continental United States are within 30 minutes of some kind of, although not necessarily an adequate, airport. As stated in NASP, if economics were put aside, the goal of NASP would be to assure an adequate airport within 30 minutes ground access time of each community. Economics is a factor, however. In order for an airport to be economically viable, it must have sufficient based airplanes and transient traffic to justify its existance.

The rule-of-thumb applied in NASP is that an airport having 10 based aircraft (or total number of engines), while not sufficient in itself to justify the airport, is likely to generate enough total activity, including transient operations, to justify the airport. There are some airports included in NASP that have less than 10 based aircraft, but are justified for other reasons such as postal service or provision of emergency services.

Again, 50 or more based airplanes are required to generate a 55 DNL area outside an airport, unless the airport is of transport size where jet operations can occur. It is assumed here that the probability of a public-use airport having more than 50 based aircraft, or being of transport size, not being included in NASP is so low that it would not affect the analyses of this study. The conclusion is that the area exposed to noise from the general aviation airports included in NASP provides an acceptable estimate of the national exposure to general aviation noise in the sense of aggregated area and population.

The 10 state sample of GA airports in NASP used in the analyses of Section 5 of this report represents 31 percent of all GA airports in NASP. Airplanes based at these airports are 38 percent of the registered fleet in 1977. Most of the general aviation airports with the largest numbers of operations, and hence largest noise exposure areas, are included in the 10 state sample. It is reasonable to assume that the aggregated noise exposure areas and aggregated population exposed to noise, for the 771 airport sample, when multiplied by 3, provides a satisfactory estimate of the national area and population exposed to community noise at 55 DNL and higher from general aviation airports for the baseline year 1975.

A problem remains as to how the projected growth in fleet size will be accommodated. The NASP incorporates a projection of

450 new reliever and small community airports by 1987. Historical trends show, however, that the number of public access airports is actually decreasing with time. A conservative estimate, that is one that would tend to overstate noise exposure, would assume that all growth will need to be accommodated at the fixed number of airports now incorporated in NASP. The estimate is conservative in the sense that no new airport area would be subtracted from the growth of total area of a DNL contour.

This assumption requires that the 2.4 to 1 growth of the overall number of GA airplanes between 1975 and 2000 would occur by a proportional growth at each airport. This is feasible at all but the very busiest existing airports which would become capacity limited. Only one GA airport (Van Nuys, CA) is so limited, where the present 1300 based airplanes would likely be limited to 2000 by 1985.

6.2 Areas Enclosed by Contours of Equal Day-Night Average Sound Level For 771 Airports

The models described in Section 5 of this report, along with the forecast fleet composition and size, allow computation of the total DNL contour area and the net area outside the airport. The computation is for three different classes of airports, as a function of the number of airplanes based at the airport, and varying for different fleet compositions and time periods. The baseline 1975 computations for basic utility, general utility, and transport airports were calculated with the models and distribution of numbers of airport, by airport size, appropriate to each airport class. The total areas are aggregated, for each DNL value, as:

$$A_{total} = \sum_{i=1}^{M} M_i \times A_i \qquad (14)$$

where A_i is the area for an airport of the i-th size, and M_i is the number of airports of that size. The net contour area outside the airport is calculated as:

$$A_{net} = \sum_{i=1}^{M} M_i (A_i - a_i) \qquad (15)$$

where a_i is the airport area for the i-th size airport.

Areas for airports in the basic and general utility classes for the years from 1980 to 2000 were calculated by increasing the number of small prop operations at each size airport by the multipliers listed in Table 13 (on page 5-26) for the separate time periods. Areas for the transport airport class were calculated by increasing the airport operations by the same time period multipliers, while somewhat offsetting this increase by the decrease in composite fleet sound levels at the different time periods.

The results of these computations are summarized in Table 14 and Figure 34 for utility airports, Figure 35 for transport airports, and Figure 36 for the aggregate of utility and transport airports. Figure 34 displays the growth of net contour area of utility airports due to the exapnsion of the small prop fleet. Figure 35 illustrates the decrease in 60 and 65 DNL net contour area at transport airports, due to a decrease in jet fleet sound levels, but with the 55 DNL area remaining essentially constant.

TABLE 14

771 AIRPORT SAMPLE - AREAS EXPOSED TO VARIOUS DAY/NIGHT AVERAGE SOUND LEVELS

Area in Square Miles

		432 Basic Utility		214 Gen. Utility		125 Transport		771 Total	
Year	DNL	Total Area	Net Area	Total Area	Net Area	Total Area	Net Area	Total Area	Net Area
1975	55	52.9	10.4	57.6	8.4	410.7	306.5	521.2	325.3
	60	15.0	0.2	16.3	0	184.0	80.0	215.3	80.2
	65	4.2	0	4.6	0	82.4	4.5	91.2	4.5
	70	1.2	0	1.3	0	36.9	0	39.4	0
1980	55	67.9	16.8	73.8	15.2	377.2	273.0	518.9	305.0
	60	19.2	0.7	20.9	0.1	162.2	63.8	202.3	64.6
	65	5.4	0	5.9	0	69.8	1.7	81.1	1.7
	70	1.5	0	1.7	0	30.0	0	33.2	0
1985	55	89.9	29.1	97.8	27.0	343.7	239.5	531.4	295.6
	60	25.4	2.1	27.7	0.8	142.3	37.9	195.4	40.8
	65	7.2	0	7.8	0	58.9	1.1	73.9	1.1
	70	2.0	0	2.2	0	24.4	0	28.6	0
1990	55	107.7	40.9	117.2	41.0	268.1	163.8	493.0	245.7
	60	30.5	2.8	33.2	1.8	88.7	12.8	152.4	17.4
	65	8.6	0	9.4	0	29.4	0	47.4	0
	70	2.4	0	2.7	0	9.7	0	14.8	0
1995	55	124.7	54.3	135.7	59.2	270.9	166.7	531.3	280.2
	60	35.3	4.5	38.4	2.9	83.7	12.9	157.4	20.3
	65	10.0	0	10.9	0	25.9	0	46.8	0
	70	2.8	0	3.1	0	8.0	0	13.9	0
2000	55	139.1	67.4	151.4	73.8	284.7	180.6	575.2	321.8
	60	39.4	5.6	42.8	4.0	83.1	14.4	165.3	24.0
	65	11.1	0	12.1	0	24.3	0	47.5	0
	70	3.1	0	3.4	0	7.1	0	13.6	0

Total area includes airport.
Net area excludes airport.

Multiply by 3 to estimate national exposure.

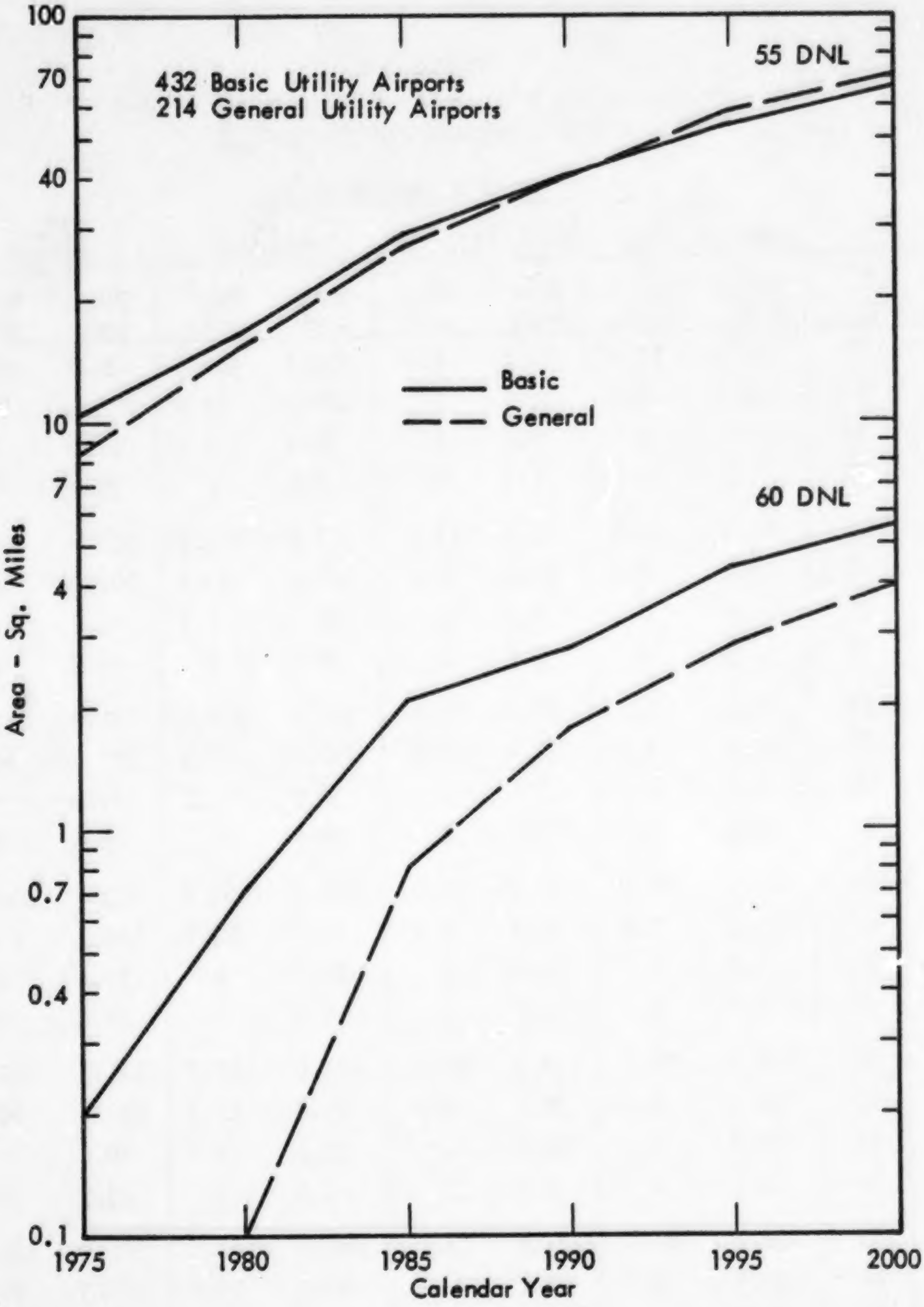

FIGURE 34. CUMULATIVE DNL AREA OUTSIDE UTILITY AIRPORTS

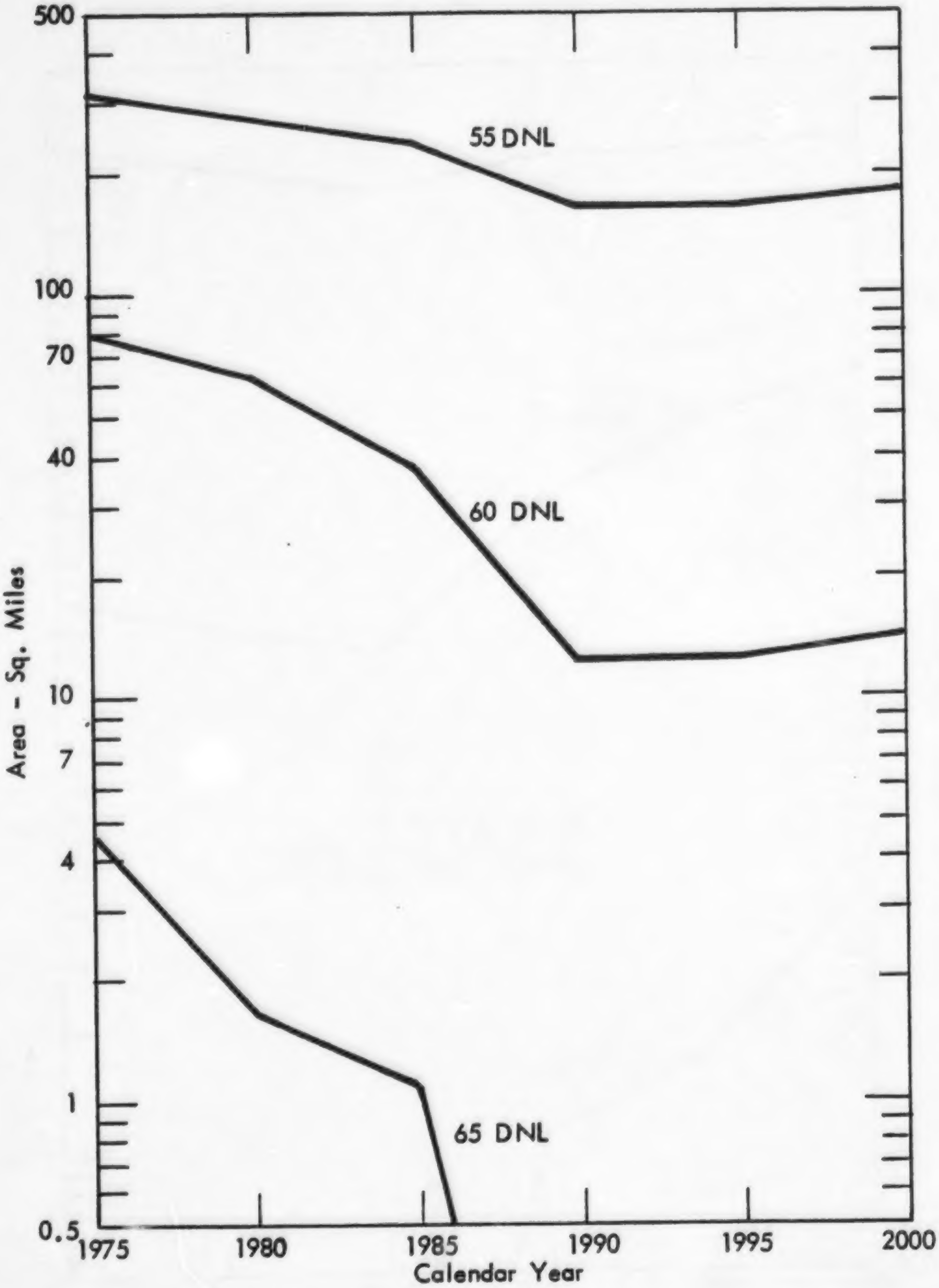

FIGURE 35. 125 TRANSPORT AIRPORTS - CUMULATIVE DNL AREA OUTSIDE AIRPORTS MIXED FLEET - 2% JETS

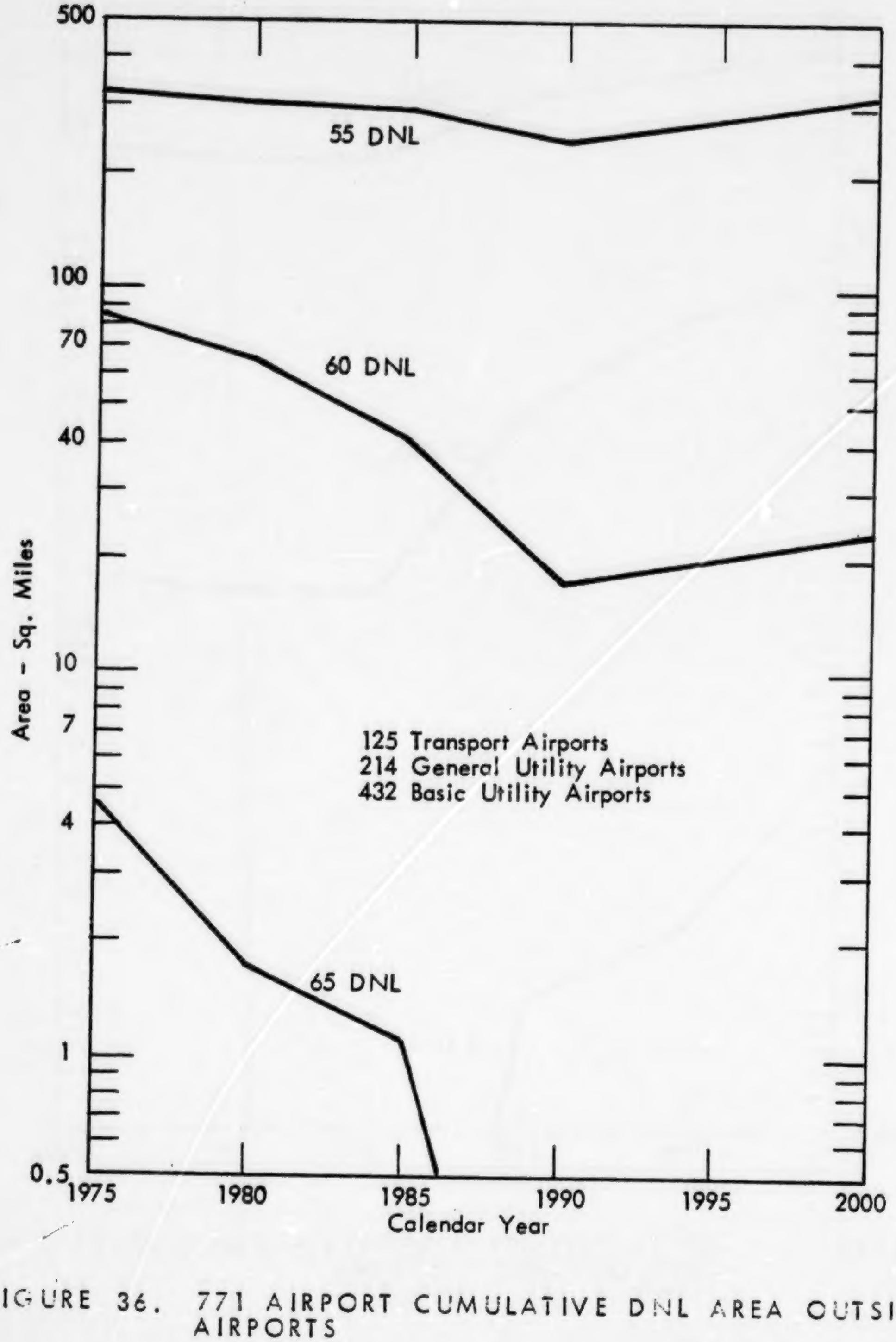

FIGURE 36. 771 AIRPORT CUMULATIVE DNL AREA OUTSIDE AIRPORTS

6.3 Population Exposed to Various Day/Night Average Sound Levels For the 771 Airport Sample

The net contour areas, by class of airport, were used to estimate the population contained within the 55, 60, and 65 DNL contours. In order to make this computation, airports in each airport class were segregated into the three population classes, rural, suburban rural, and urban, as discussed in Section 5. This assignment is summarized in Table 15. The aggregated net contour areas for each airport class, segregated by population class, are listed in Table 16.

The populations exposed to different levels of DNL, for each airport class, were calculated by multiplying the areas within each population class by the following population densities:

Rural	50 people per square statute mile
Suburban-Rural	200 people per square statute mile
Urban	5000 people per square statute mile

The results of this computation are listed in Table 17. Using a multiplier of 3, the estimated national population exposure is listed in Table 18.

TABLE 15

771 AIRPORT SAMPLE - DISTRIBUTION OF AIRPORTS BY NUMBER OF BASED AIRPLANES CLASS

Based	Basic Utility			General Utility			Transport		
Airplanes	Urban	Suburb	Rural	Urban	Suburb	Rural	Urban	Suburb	Rural
1		1	4			2			2
2		2	2	1		0			
3		4	5			1			1
4.5	1	15	4		1	1			1
6	1	11	8			3			
7.5		8	3		3	1			
9	2	29	21		2	2		1	1
11.5	1	29	13		1	6			1
14	3	31	30		4	8			7
18	1	26	15		8	13		3	6
23	4	22	16	2	6	10		4	4
29		17	9	1	16	12	1	4	7
36	6	10	12		9	5	1	4	8
45		5	3	1	5	11	1	5	4
57	3	7	5	3	11	8		5	5
73	4	6	6	1	8	6		2	3
90	0	5	1	2	4	7		4	3
115	0	6		2	4	5		2	
150	1	2	1	1	1	2	2	4	6
180	2				2	2	1	2	3
225	1		1	1	1	0	2	2	
300		2		3	0	1	1		1
375		2		1	0	0	1		
450	2				1	0	4	2	2
475	1				1	1			
730								1	
900									
1150									
1500							1		
Total Airports	33	240	159	19	88	107	15	45	65

TABLE 16

771 AIRPORT SAMPLE - AREA OUTSIDE AIRPORT
EXPOSED TO VARIOUS DAY/NIGHT AVERAGE SOUND LEVELS
SEGREGATED BY AIRPORT SIZE AND POPULATION CLASS

	Area in Square Miles					
	1975	1980	1985	1990	1995	2000
55 DNL						
Basic Utility						
Urban	5.22	7.54	11.65	15.20	18.59	22.11
Suburban	4.46	7.63	13.46	19.26	25.96	32.64
Rural	0.74	1.63	3.99	6.48	9.75	12.65
Total	10.40	16.80	29.10	40.94	54.30	67.40
General Utility						
Urban	2.73	4.74	7.98	10.80	14.36	17.05
Suburban	3.23	5.65	9.94	15.19	22.93	27.37
Rural	2.47	4.81	9.98	15.01	21.91	29.38
Total	8.43	15.20	27.90	41.00	59.20	73.80
Transport						
Urban	69.80	64.20	59.71	50.78	52.92	57.33
Suburban	108.66	96.25	83.90	55.78	56.94	62.11
Rural	128.01	112.55	95.89	57.26	56.84	61.16
Total	306.47	273.00	239.50	163.82	166.70	180.60
60 DNL						
Basic Utility						
Urban	0.24	0.66	1.31	1.53	2.55	3.10
Suburban	0	0	0.76	1.20	1.70	2.15
Rural	0	0	0.03	.11	.22	0.31
Total	0.24	0.66	2.10	2.84	4.47	5.56
General Utility						
Urban	0	0	0	0.28	0.74	1.18
Suburban	0	0.07	0.48	0.90	1.23	1.61
Rural	0	0.07	0.34	0.63	0.91	1.17
Total	0	0.14	0.82	1.81	2.88	3.96
Transport						
Urban	22.56	18.53	15.01	7.01	6.45	7.06
Suburban	25.82	18.45	12.00	3.22	3.19	4.00
Rural	31.62	26.82	10.89	1.67	1.66	0.94
Total	80.00	63.80	37.90	11.90	11.30	12.00
65 DNL						
Transport						
Urban	3.09	1.29	0.96			
Suburban	0.97	0.40	0.17			
Rural	0.39	0	0			
Total	4.45	1.69	1.13			

TABLE 17

771 AIRPORT SAMPLE POPULATION EXPOSED TO VARIOUS DAY/NIGHT AVERAGE SOUND LEVELS

	Population in 1,000's					
	1975	1980	1985	1990	1995	2000
55 DNL						
Basic Utility	27.0	39.1	61.2	80.2	98.7	117.7
General Utility	14.4	25.1	42.4	57.8	77.7	92.0
Transport	377.1	345.9	320.1	268.0	278.7	302.0
Total	418.5	410.1	423.7	406.0	455.1	511.7
60 DNL						
Basic Utility	1.2	3.3	6.7	7.7	13.1	16.0
General Utility	0	0	0.1	1.7	4.0	6.3
Transport	119.7	97.5	77.9	35.7	33.2	36.3
Total	120.9	100.8	84.7	45.1	50.3	58.6
65 DNL						
Transport	15.7	6.5	4.8	0	0	0

Multiply by 3 to obtain estimate of national population.

TABLE 18

ESTIMATED NATIONAL POPULATION EXPOSED TO VARIOUS DAY/NIGHT AVERAGE SOUND LEVELS FROM GENERAL AVIATION AIRPORTS

Population in 1,000's

Year	55 DNL	60 DNL	65 DNL
1975	1,256	363	47
1980	1,230	302	20
1985	1,271	254	14
1990	1,218	135	0
1995	1,365	151	0
2000	1,535	176	0

7.0 REFERENCES

1. Federal Aviation Regulation Part 36 - Noise Standards: Aircraft Type Certification, November 3, 1969.

2. Amendment 36-2 to FAR Part 36, October 26, 1973.

3. Amendment 36-7 to FAR Part 36, October 1, 1977, and Amendment 36-8, April 3, 1978.

4. EPA recommendations to FAA for revisions to FAR Part 36, published as FAA Notice 76-22, October 28, 1976.

5. Appendix C of Reference 1.

6. Amendment 36-4 to FAR Part 36, February 7, 1975.

7. Amendment 36-6 to FAR Part 36, January 24, 1977.

8. National Airport System Plan 1978-1987, Federal Aviation Administration, 1977.

9. FAA Aviation Forecasts Fiscal Years 1980-1991, Federal Aviation Administration, September 1979.

10. General Aviation Pilot and Aircraft Activity Survey, Report No. FAA-MS-79-7, Federal Aviation Administration, December 1979.

11. Jane M. Beckman and Harry Seidman, "NOISEMAP 3.4 Computer Program Operators Manual," AMRL-TR-78-109, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, December 1978.

8.0 GLOSSARY OF ABBREVIATIONS AND SYMBOLS

Measures of Sound Level

ALM	Maximum A-weighted sound level - in decibels. The highest value obtained during a flyover using a sound level meter with slow time constant and frequency weighting.
DNL	Day-night average sound level - in decibels. The twenty-four hour mean-square average A-weighted sound level, after the addition of 10 decibels to sounds that occur between 10 p.m. and 7 a.m.
EPNL	Effective perceived noise level - in decibels. The measure of noise used in Federal Aviation Regulation Part 36 for noise certification of transport category and turbine airplanes.
SEL	Sound exposure level - in decibels. The time integral of mean-square A-weighted sound level - usually integrated over individual flyovers.

Airport Terms

BU	Basic utility airport - runways less than 3200 feet long.
GU	General utility airport - runways less than 4300 feet long
BT	Basic transport airport.
GT	General transport airport.
NASP	National Airport System Plan

Symbols

a, α	constant term in equation relating area of a sound level contour to the stated sound level
b, β	slope, or ratio of the change of the logarithm to the base 10 of the area of a sound level contour to the rate of change of sound level
A	area of a sound level contour - in square statute miles
h	height of an airplane above ground - in feet
L_{AE}	symbol for sound exposure level
$\overline{L_{AE}}$	symbol for the mean-square sound exposure level
L_{AM}	symbol for maximum A-weighted sound level
L_{dn}	symbol for day-night average sound level
L_{EPN}	symbol for effective perceived noise level
M_h	helical tip Mach number of a propeller - the ratio of the vector sum of propeller tip rotational speed and airplane forward speed to the speed of sound
N	effective number of operations - the average number of airplane takeoffs and landings in a 24-hour period, with the number occurring between 10 p.m. and 7 a.m. multiplied by a factor of 10

R^2	the coefficient of determination is the square of the correlation coefficient and indicates the amount of variance accounted for in a multiple regression
r^2	the coefficient of determination is the square of the correlation coefficient and indicates the amount of variance accounted for in a simple regression
s_e	the standard error of the mean values in a regression
V	airspeed in knots
V_2	takeoff safety speed for transport or turbine-powered airplanes
V_y	the speed for best rate-of-climb for propeller-driven small airplanes